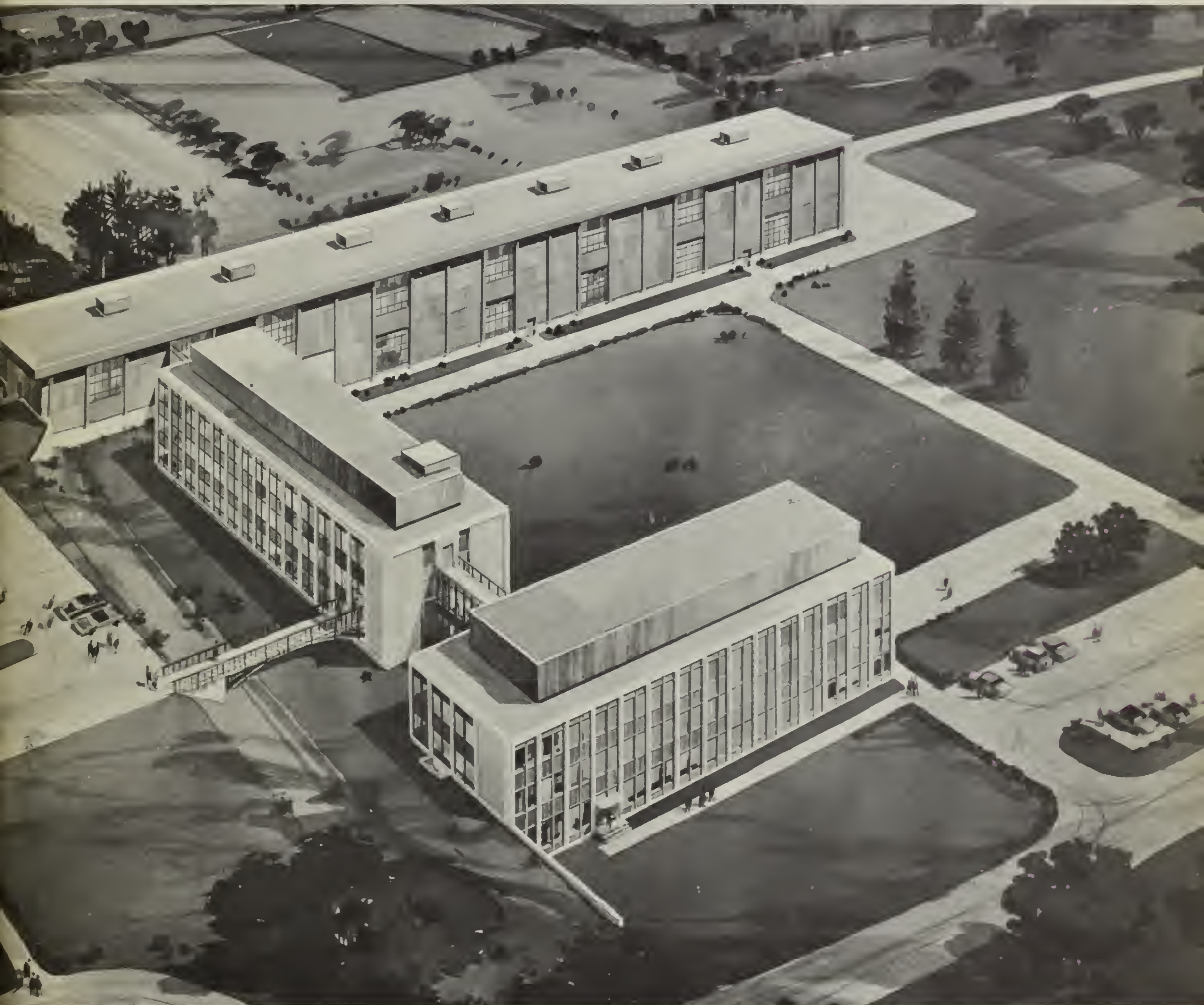
FPL 1964



ANNUAL REPORT OF RESEARCH

at the FOREST PRODUCTS LABORATORY

FOREST SERVICE / U. S. DEPARTMENT OF AGRICULTURE

FPL 1964

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FPL 1964:

Annual Report of Research at the Forest Products Laboratory

FOREWORD

Research progress at FPL received renewed stimulus during 1964 when the Congress of the United States provided funds for a major expansion of the physical plant. Just as the acquisition of knowledge through research builds up creative forces that stimulate industrial growth and development, so does research progress generate new needs within any institution that contributes to those creative forces.

The Congressional appropriation of $3.8 million for new construction represented the first major provision for new research facilities since the present main building was occupied in 1932. These facilities, representing the first phase of a three-stage program, will be constructed and put to use as expeditiously as possible. We look forward confidently to a re-energizing of our research program that will transmit fresh stimuli to progress throughout the forest industries.

Meanwhile, our present program continues to be productive of useful results. Large credit for this must of course go to a creative staff that has proven itself equal to the challenges of the many problems confronting us. Among accomplishments of the past year have been these highlights:

- Discovery that a constituent of wood tissue nutrients known as myo-inositol and found in all organic substances is uniquely essential for growth of cambial cells.
- Completion of a wood density study on nine species conducted by core sampling living trees in 11 western States.
- Bench-scale development of a new process for recovering chemicals in the spent pulping liquor of a new high-yield FPL polysulfide kraft process to enhance commercial attractiveness of the process.
- Evolution of new techniques for evaluating tensile and compressive properties of full-size structural members, to make possible development of more efficient engineering design methods with wood.
- Origination of a new design theory to permit safe design of flat roofs subject to water ponding.
- Construction of an experimental structure for study of various materials, building components, wood treatments and finishes, and radiant temperature control with infrared heat.
- A new technique for rapid evaluation of glue joints in production quality control.
- New findings on the decay process that point to hitherto unrecognized differences in microstructure of hardwoods and softwoods.
- An oxidation process for inducing free radicals in lignin model compounds that provides a promising new tool for elucidating the molecular character of lignin.

Information on these and many other developments of FPL research during the past year is presented in this report. A complete list of the year's publications is appended.

Edward G. Locke

EDWARD G. LOCKE
Director

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THE YEAR IN GENERAL

Among the many research-related activities that marked the year 1964 at FPL, the most significant and pervasive was the planning for future growth. This activity received strong stimulus at midyear, when the Congress appropriated funds for construction of a three-unit addition to house new facilities for research in wood fiber products and wood chemistry. President Lyndon B. Johnson signed the appropriation bill into law on July 7.

Because funds for engaging architects had been voted 2 years earlier, planning was well advanced when the construction funds became available. The general layout and type of buildings had been decided upon. Nevertheless, a multitude of final decisions became necessary when the actual sum available for building was fixed by the appropriation. These ranged from choices as to floor surfaces to final fixing of building sizes and types and location of major equipment. From this final burst of planning activity there emerged at year's end a definite concept shaped by joint action of FPL staff, the architects, and the Federal Government's General Services Administration.

Basically, the addition will provide nearly 117,000 square feet of gross floor space in three buildings. The largest will be a new pilot plant for research on pulp and paper and other wood fiber products. It will be 460 feet long, 48 feet high, and 60 feet wide and constructed largely of wood. For one-half its length it will be of single story construction; the other one-half will have two floors. Laminated wood arches will

Part of the land on which a new addition to FPL will be built was given a preliminary scraping in late autumn to remove topsoil inoculated with pea root fungus and used for long-time experiments by University of Wisconsin College of Agriculture. Soil was transferred to another site for continuation of experiments in developing fungus-resistant plants.
M 127 899

span the full width to provide completely unobstructed floor area so desirable under continually changing conditions of use. Walls will be enclosed with structural sandwich panels with plywood faces, and the roof will be decked with lumber.

The pilot plant will replace experimental pulping and papermaking facilities now located on six floors of the present main building — suitable for batch-type pilot experiments but not for continuous pulping and papermaking research for which the new facilities are planned.

Both of the other buildings will be 167 feet long and 51 feet wide. One, three stories high, will house laboratories for wood chemistry research and administrative offices of the two divisions. The other, four stories high, will be used for laboratories by both divisions.

The ground floor of the wood chemistry unit will house pilot-plant equipment for research on wood hydrolysis, hydrogenation, fermentation, and other processes for converting wood to sugars, yeasts, industrial acids, chemical intermediates for plastics and synthetics, and other industrial raw materials. Part of the first floor will house laboratories designed specifically for research on wood with radioactive materials — an area of investigation in which work has been greatly limited by lack of suitable space and facilities. Other laboratories for research on wood and bark will also be on this floor. The second floor will be devoted mainly to analytical laboratory facilities — a function of the division that serves all other research activities as needed — and the administrative offices of both divisions.

Dr. Robert Koeppen, left, and Dr. B. F. Kukachka examine herbarium material — leaves, flowers, and fruit — of a new species of nutmeg tree discovered in the Amazon valley of Peru and named **Virola kukachkana** in Dr. Kukachka's honor by Dr. Louis O. Williams, curator of Central American botany at the Chicago Natural History Museum. Dr. Kukachka is directing the collection, identification, and evaluation of Peruvian woods.
M 126 049

The third building will house mechanical equipment for the entire addition on its ground floor. The first, second, and third floors will be devoted mainly to laboratories for research on wood fiber products.

Each laboratory will be located on one side of a central corridor. Across the corridor will be an office for the scientists using the laboratory. The basic laboratory will be 11 feet wide and 24 feet long. Nonload-bearing partitions, however, will make it convenient to enlarge laboratories in multiples of the 11-foot module. Offices will be basically 11 by 14 feet and similarly expansible.

The three buildings will be arranged in a U pattern and will be connected by enclosed passages.

Both of the smaller buildings will have exterior spandrel panels of wood. The fan lofts on their roofs will have walls faced with vertical wood siding. Administrative offices will be paneled with wood.

During the late months of 1964 dismantling of several auxiliary buildings was begun to make way for the new structure. Notable among these was an historic two-story experimental house of stressed-skin panel construction originated by FPL research engineers in the early 1930's. This house was built in 1938. When it became necessary to remove it, final evaluations were made of its structural rigidity as it stood on its foundation; these are described under the section of this report headed Wood Engineering Research. A companion one-story house will be removed to another site on the Laboratory grounds as the nucleus, along with a sandwich experimental unit erected in 1937, of a housing research park.

The new construction to begin in 1965 will constitute the first phase of a three-phase expansion of FPL. The second phase is planned to consist of remodeling the present main building and some auxiliary structures to make more efficient use of space vacated by the Divisions of Wood Fiber Products and Wood Chemistry Research. The third phase will consist of construction of new research facilities for the Division of Solid Wood Products Research. Both the second and the third phase, of course, are contingent upon availability of funds.

Among research-related activities of FPL during the year were many meetings both here and else-

where with representatives of industry, Government, and scientific and educational organizations. A resume of this and other activities of an educational and informational character is given elsewhere in this report.

The more unusual activities included a trip to Alaska by two staff engineers to study the kinds of damage done to houses and other buildings by the Good Friday earthquake. The forces unleashed by this natural phenomenon exceed, of course, anything possible in a laboratory, and, while uncontrolled, offered a unique opportunity to learn more about types of construction that can and cannot endure the stresses imposed.

A unique distinction befell another staff member. A new species of tree discovered in South America was named for Dr. B. Francis Kukachka, who is in charge of FPL wood identification and structure research. The tree, identified as of the genus *Virola* and family Myristicaceae, is now recorded in the botanical literature as *Virola kukachkana.*

FPL's function as national center of the Forest Service for research on wood is complemented by projects and studies under way at 10 Forest Experiment Stations. In general, FPL research is aimed at developing knowledge that is adaptable or applicable anywhere in the United States at the least possible cost. Adaptation and application of this information to regional requirements constitute a major part of the research function of the Stations in the area of forest products. Broadening and strengthening this work are studies in forest engineering, economics, and forest products marketing. The Stations, of course, have many other research assignments, such as forest and range management for the production of timber, water, forage, wildlife habitat, and recreation; protection of the forest and range resources from fire, insects and diseases.

An account of the year's research progress at FPL is presented in the following pages in five sections corresponding to the five technical divisions: Wood Fiber Products Research; Wood Engineering Research; Solid Wood Products Research; Wood Quality Research; and Wood Chemistry Research.

WOOD FIBER PRODUCTS RESEARCH

The high promise of the new FPL polysulfide process for substantially greater kraft-type pulp yields, announced in the 1963 Annual Report, was brought much nearer to commercial realization at FPL during 1964 with the discovery of an efficient process for recovery of reusable chemical from the sulfur-enriched spent liquors. Besides enhancing the economy of the pulping process, the new recovery system reduces the hazard of polluting waterways with oxygen-consuming effluent and promises reduction of air pollution. Polysulfide pulping promises up to one-fourth more pulp from a given amount of wood than is obtained by conventional kraft pulping. The new recovery process, moreover, has advantages for other pulping processes.

Among other noteworthy developments in wood fiber products research during 1964 were new findings on the relationship of papermaking variables, such as fiber orientation in the sheet to strength and elastic properties of paper; a method of measuring shear strength of paper, important in the design of many products; new information on the relation of various starch treatments to surface and strength properties of paper; data on the effects of different pulp refining methods on properties of softwood-hardwood pulp blends; and new visual evidence of the relative bonding capabilities of different kinds of pulp.

Polysulfide Pulping

By far the most heavily used pulping process in the United States is the sulfate, or kraft. Well over one-half of all wood pulp produced in the United States is kraft — 17,493,000 tons in 1963 out of a total of 29,435,000.

These production figures dramatize polysulfide's potential. Full realization of that potential over a period of years could mean a production increase of some 3 million tons from a given amount of wood. Or, conversely, the same 1963 production level could be maintained with 5 million fewer cords of pulpwood. Since expanding population trends and other economic projections all point to large increases in paper consumption, adoption of polysulfide pulping would in all probability result in greater production of pulp rather than lower consumption of pulpwood. At current prices, the additional pulp from the same amount of pulpwood would be worth some $350,000,000, whereas maintenance of current production levels would be reflected in a saving of some $125,000,000 to manufacturers in pulpwood costs.

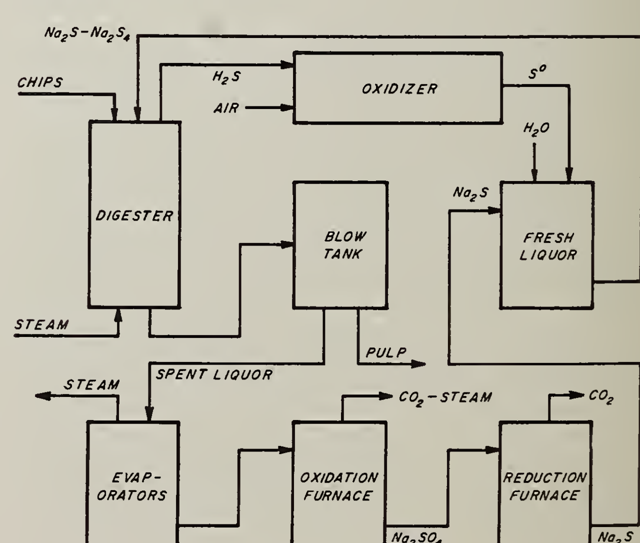
In this economic setting, the potential of polysulfide pulping is greatly enhanced, therefore, by development during the past year of a highly promising recovery process for reuse of the pulping chemicals and accompanying improvement of pollution control. This process has worked well in laboratory experiments. Pilot-scale and full commercial evaluations of its practicality remain to be done. It is expected, however, that these will be forthcoming in cooperation with industry.

The FPL recovery process provides for recapture of hydrogen sulfide generated in the digester during cooking of the pulp, and for reconversion of the spent (black) liquor by evaporation, oxidation to sodium sulfate, and reduction to sodium sulfide.

The hydrogen sulfide is stripped from the digester with steam and oxidized to obtain elemental sulfur. This increases the alkalinity of the cooking liquor and substantially reduces the requirement for active alkali. The ratio of sulfur to alkali in the liquor remaining in the digester can be so adjusted that recovery processing of the spent liquor produces 100 percent sodium sulfide. Hence there is no need for the lime kiln and causticizing system required in conventional kraft pulping, elimination of which may well offset the capital cost of the additional recovery-system apparatus. Pilot and full-scale commercial trials of the process may establish that only a single-step furnace operation is needed to convert the dehydrated black liquor to sodium sulfide.

The recovery process is, of course, also suitable for use with conventional kraft pulping with liquor at 100 percent sulfidity, as well as with the alkaline sulfite and other modifications of these processes.

Flow chart for system designed to recover sodium from spent polysulfide liquor.
M 128 425



Indications are that its use would permit substantial savings in capital cost and heat requirements, as well as reducing air pollution.

The type of specific chemical reaction responsible for the increased yield obtained by polysulfide pulping was established in experiments to determine the reaction of pure cellulose with alkaline polysulfide. These explained the improved resistance of cellulose toward alkaline degradation by showing that part of the reducing end groups are rapidly oxidized to mannonic acid. This aldonic acid end group apparently forms by direct oxidation and simultaneous isomerization and epimerization reaction of the reducing end groups. It is completely resistant to the alkaline peeling reaction, in this respect being like gluco-metasaccharinic acid, which is known to form slowly and to be solely responsible for stopping the peeling action in conventional kraft and other alkaline pulping processes. The findings were reported at a national meeting of the American Chemical Society.

Magnesia-Base Pulping

Experiments demonstrating the good promise of magnesia-base sulfite liquors instead of the soda-base liquors commonly used in neutral sulfite chemical pulping were reported in the 1963 Annual Report. The comparatively simple and economical recovery of magnesia as compared with soda was shown to offer distinct advantages in reducing pollution as well as offsetting the initially higher cost of the magnesia. During 1964 the process was shown to be commercially feasible in a trial run at a corrugating board mill of a cooperator in the study.

New Sulfite Recovery Process

Oxidation experiments with a synthetic smelt made of sodium sulfide and sodium carbonate in equal parts to represent the principal ingredients of the smelt of a neutral sulfite semichemical mill gave favorable indications as a potential sulfite recovery system for use with NSSC spent liquor. The synthetic smelt was enriched with sulfide to obtain the 3:1 ratio of sodium sulfide to sodium carbonate used in the neutral sulfite pulping liquor.

Success of the process hinges on proper control of certain unusual variables, such as the molar ratios of sodium carbonate and sodium sulfide to water present in the smelt. Indications are that, with optimum operating conditions, 80 percent or more of the sodium sulfide can be converted to sodium sulfite by direct oxidation.

Mechanical Pulp Treatments

The different effects of pulp processing on hardwoods and softwoods are under investigation to find ways of expanding the use of hardwoods in kraft papers and boards, such as wrapping, multiwall bag, and linerboard for corrugated boxes. Hardwood use at present is limited to, at most, 15 to 20 percent of the total; greater proportions have an adverse effect on certain properties of these high-volume products.

Hardwoods are usually combined with softwoods before pulping or processing, which is done usually in equipment designed for softwoods. FPL processing experiments are being conducted separately on softwood and hardwood pulps to develop the best properties of each before blending them.

In comparing disk with conical refiners, for example, a high-angle conical refiner has been found to develop more effectively the potential bursting and tensile strength of hardwood pulps and preserving their initial tearing resistance. The disk refiner, however, appears to be more suitable for treating softwood pulps.

A 50/50 mix of aspen kraft pulp refined in a disk refiner and disk-refined pine kraft pulp had better overall strength characteristics than a similar blend of these pulps that had been refined separately or together in either type of refiner. Some other softwood-hardwood blends, however, were little different in properties whether refined separately or together. Research is continuing to establish more clearly the significance of such basic differences as fiber length and cell composition between hardwoods and softwoods on property development under specific types of processing.

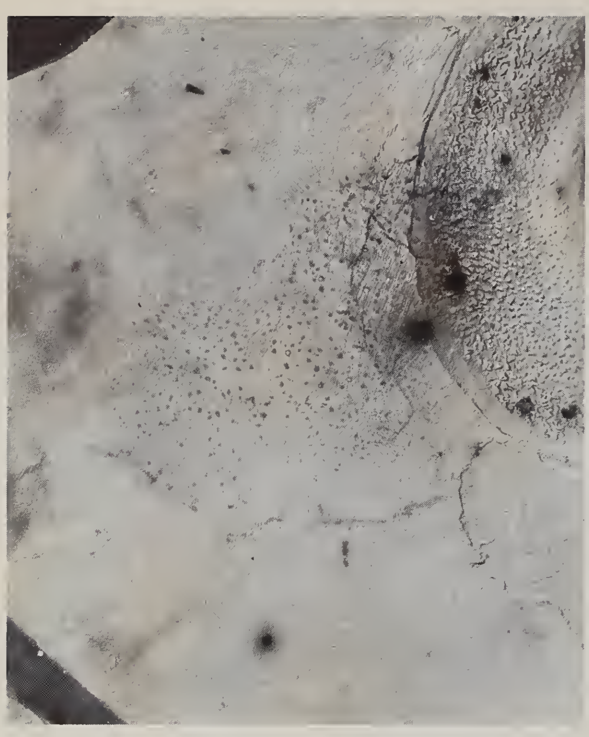
Fiber Bonding

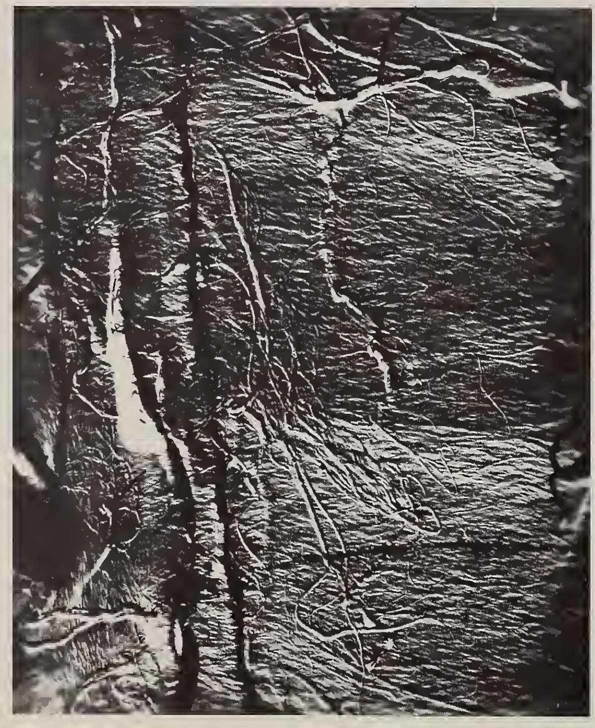
The electron microscope has revealed pulp fiber surface characteristics that lead to better understanding of why differences in fiber bonding exist between different types of wood pulps.

The predominant natural bond between two fibers is a linkage between two hydroxyl groups, creating a socalled hydrogen bond. Formation of such bonds between fibers is, of course, basic to paper sheet formation and strength. The more such hydroxyl groups there are present on the fiber surface, the more bonds can be formed. Consequently, the nature of the fiber surface has a major role in the formation of hydrogen bonds.

Pulp processing has much to do with the kind of fiber surface produced. Electron microscope studies of fiber surfaces in pulps of different kinds have shown pronounced differences. Surfaces of softwood kraft pulp fibers, for example, are considerably more wrinkled than those of sulfite pulp fibers. This is important in bonding one surface to another, since the hydrogen bond can form only across an extremely short distance, about 157 millionths of an inch.

Pronounced differences were shown to exist between the surfaces of high-yield and fully cooked balsam fir pulps prepared by the sodium bisulfite process. Electrongraphs of the surfaces of the high-yield pulp fibers have shown a residue of lignin that





Electrongraphs reveal why high-yield pulps have lower fiber-to-fiber bonding potential than fully digested pulps. Top, balsam fir sodium bisulfite pulp of 94.5 percent yield has smooth surface on which lignin residue blocks off hydroxyl groups necessary for hydrogen bond formation. Bottom, much more wrinkled appearance of balsam fir sodium bisulfite pulp cooked to 48 percent yield reveals many more opportunities for hydrogen bond formation.
M 128 424

blocks off many of the hydroxyl groups of the cellulose. On the low-yield, fully cooked pulp fiber surfaces, however, strands of many cellulose fibrils are clearly visible, and these, of course, have high potential for fiber bonds.

Dissolving Pulps

Highly purified wood pulps — with all possible lignin and hemicellulose removed — are widely used for manufacture of rayon, explosives, plastics, and other products. The most common type of pulp so used is prehydrolysis-kraft, which is so called because the chips are treated with water to remove some of the hemicellulose before being pulped in conventional kraft liquors. The pulps are then treated with chlorine to remove residual lignin, washed in water to remove chlorine, and given a final purification with caustic soda. This extraction treatment may be done with chemicals at room temperature (cold extraction) or up to 70° Centigrade (hot extraction).

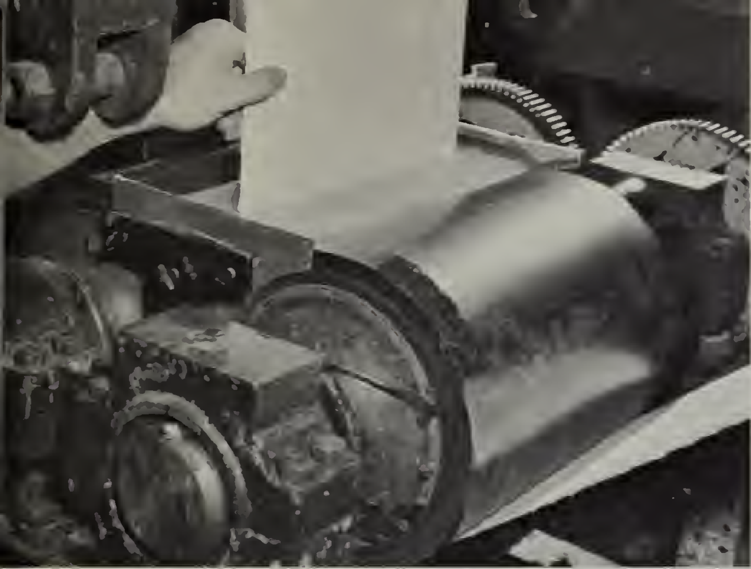
The effects of these various steps in preparation of dissolving pulps for either viscose or acetate processing were analyzed by studying the swelling characteristics of fibers from pulps made under various conditions — longer or shorter prehydrolysis time, hot versus cold extraction, and both hot and cold extraction. The findings explain much about the processing effects that has not heretofore been apparent. Among findings were:

1. The longer the prehydrolysis treatment, the more the fibers swell when treated with cellulose solvent (cadmium ethylenediamine).
2. Fibers from pulps purified by hot extraction swell more than those given cold extraction.
3. Cold extraction causes both layers of the secondary fiber wall to dissolve at about the same rate in those pulps given the longer prehydrolysis treatment.
4. The tertiary (innermost) part of the fiber wall resists solution even in pulps given the most drastic prehydrolysis and purification treatments.
5. In pulps purified by both cold and hot extraction, the secondary and tertiary parts of the cell wall dissolve at essentially the same rate in the swelling agent used.

The swelling characteristics of the different parts of the fiber walls thus give the first clear index of the effects of the pulping variables involved in production of prehydrolysis-kraft dissolving pulps. Importance of this information is seen in such known facts as that as little as 2 percent of the hemicellulose xylan can seriously affect the color of acetate yarn, and that incomplete solution of cell walls can leave residues that seriously impair strength of tire-cord rayon.

Effects of Starch Treatments

Starches and various chemicals are used to im-



Paper sheet being formed on FPL paper machine is impregnated with starch as it passes through nip between rolls of horizontal size press.
M 128 357

prove such printing and writing properties as ink receptivity and fiber picking. They may be added when the stock is prepared for the paper machine or while the sheet is on the machine. FPL research during the past year has established the optimum conditions for the use of starch to impart printing properties as well as strength to paper products.

For such printing qualities as surface strength, opacity, and ink resistance, starch should be applied so that it will remain on the surface rather than penetrate into the sheet. This can best be achieved by treating the sheet after it is relatively dry, at about 5 or 10 percent moisture content, or by using a starch mixture of high solids content or high viscosity.

On the other hand, penetration of chemical below the sheet surface improves certain strength properties without affecting sheet porosity. If this is desired, therefore, the starch mixture should be applied while the sheet is still at a high moisture content on the paper machine, or a mixture of low viscosity should be used. Penetration can also be promoted by applying high press pressure to force it into the sheet.

Burst and tensile strength can be just as greatly improved, however, by addition of 1 to 1.5 percent of starch to the surface as by twice this amount dispersed through the sheet thickness.

This study has already provided valuable information which is being used by paper manufacturers producing a variety of paper products. A 5 percent increase in efficiency in the use of starch will, it is estimated, amount to a yearly saving of $5 million.

Engineering Properties of Paper

The standard strength evaluations of paper used in the industry, such as burst and tear, have no relation to conventional strength properties of other materials. There is, therefore, no way of using these properties in the design of structures according to established engineering principles.

FPL research in this area is directed toward establishing basic methods of evaluating paper in terms of conventional strength properties such as tension, compression, and shear. During 1964 a method was devised for evaluating the strength and elastic properties of paper subjected to edgewise shear stresses. Data thus far indicate that shear strength is much lower than edgewise tensile strength.

Shear properties are important, of course, in the design of many paper products. Structural panels resist racking stresses to the extent of their shear strength. Determination of this property is essential, therefore, if paper is to be more widely used for structural purposes.

Fully as important as methods of determining strength properties are methods of improving them. In paper, of course, this can be done mainly through manipulation of papermaking process variables. Experiments with one pulp furnish during the year demonstrated how fiber orientation in the sheet and the degree of restraint and stretching applied to the wet web of paper as it dries affect and control the strength and elastic properties of handsheets subjected to tensile stress. Nine-fold differences were obtained in modulus of elasticity and three-fold differences in tensile strength. Stiffness and strain to failure were shown to be dependent primarily on the amount of shrinkage or stretch occurring during manufacture of the sheet. Tensile strength was found to depend mainly on fiber orientation.

This experiment showed that, for paper made from a given pulp, a much wider range of tensile properties is possible than is ordinarily attained in commercial practice. It also points out the steps to be followed in paper manufacture to achieve a desired balance between strength and elastic properties for products designed with given end uses in mind.

Apparatus for shear testing of paper is adjusted by Technologist Vance Setterholm.
M 124 964

WOOD ENGINEERING RESEARCH

Basic research on wood as an engineering material was highlighted during 1964 by the development of ways to determine the compressive and tensile strength of full-scale wood structural members. The significance of these new techniques derives from the fact that, as structural design becomes more refined, the strength properties of such widely used wood elements as laminated beams, wall studs, and roof-truss parts must be more precisely determined. A key factor in the continued and extended structural use of wood is increased ability to use it more intensively — that is, to exploit its strength properties more fully.

Other noteworthy developments in FPL engineering research during 1964 included evaluations of prototype structural elements, old and new, for housing; surveys of dimension lumber to determine how well new mechanical grading devices are performing; a method of reducing the effects of production variables on the strength of corrugated container fiberboard; and determinations of the suitability of several little-used western species for use in pallets.

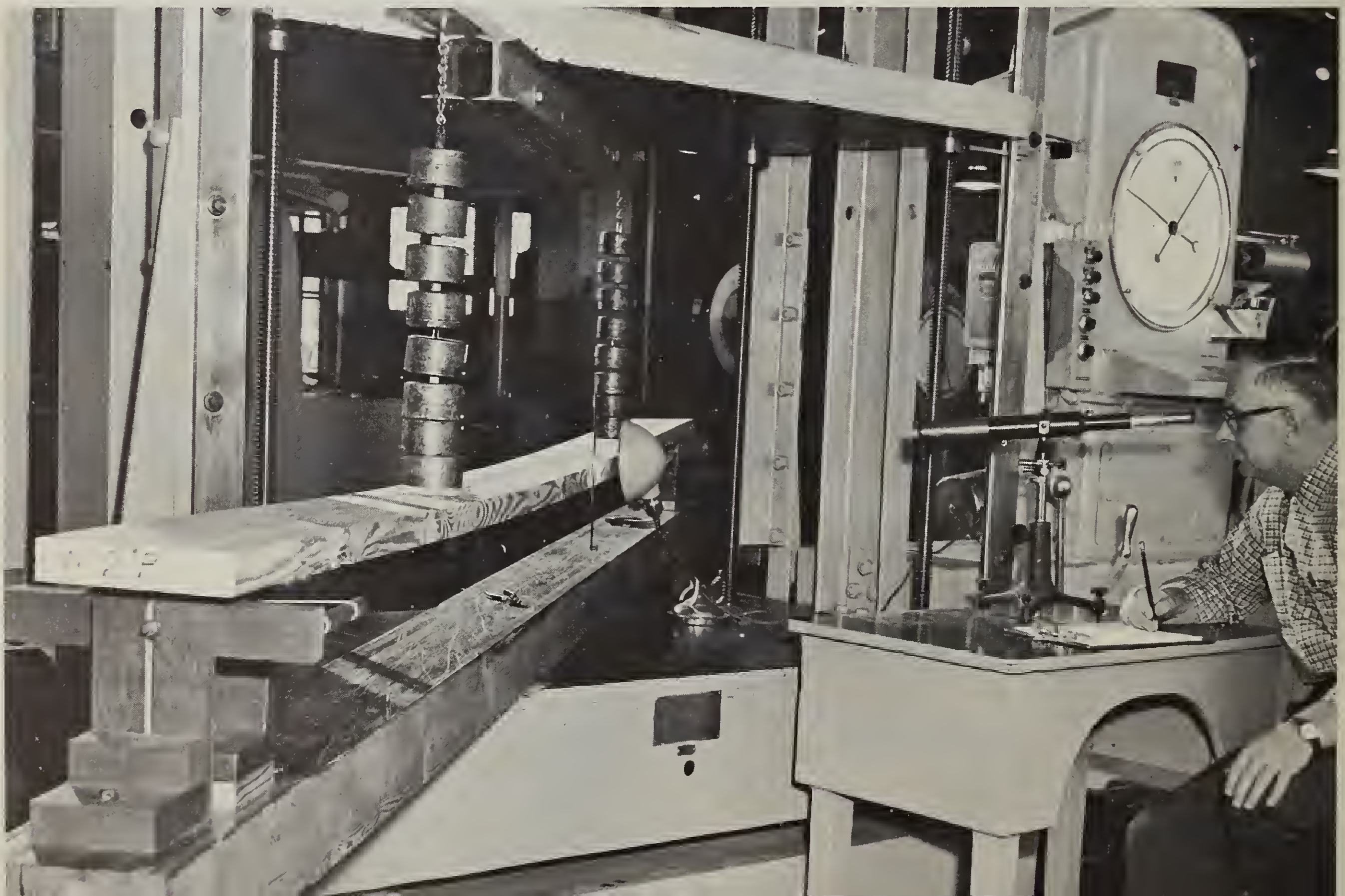
Basic Engineering Properties

Engineering research applications of the 11-State western woods density survey conducted during the past few years (see Annual Reports for 1962 and 1963), and discussed more fully herein under Wood Quality Research, were developed for the eight major commercial softwoods and one hardwood species. The density survey gives a far broader and more statistically reliable sampling of the range of specific gravity for each species than has ever before been available for determination of averages.

Relationships between strength properties and specific gravity of wood established by previous research were utilized to determine more precisely the average value of important properties for each species on the basis of the new specific gravity data. A "variability index" was established for each species that gives an indication of the average strength properties that may be expected from the material of lowest strength group available from a combination of species. The variability indices for the various strength properties furnish a sound technical basis for combining species of similar properties into groups suitable for marketing and structural use. The species involved are Douglas-fir, white, California, red, grand, noble, and Pacific silver fir, western hemlock, western larch, and black cottonwood.

Nondestructive testing of primary wood products during manufacture is attracting keen industry interest as a means of better quality control. Potential

Weights successively lowered on face of piece simulate small increments of load applied by stress-rating machines now coming into use to grade framing lumber. Relation of nondestructive proof load to deflection indicates stiffness of piece.
M 126 274



production uses include detection of defects, evaluation of key strength and stiffness properties, and control of dimensions, moisture content, surface conditions, density variations, and manufacturing defects such as glue line voids and bond quality.

Effective means for nondestructive testing are directly related to basic mechanical and physical properties of wood. For example, a study of the relation of the dynamic modulus of elasticity to the modulus of rupture, conducted on two groups of relatively low-grade material, showed good correlation. The findings, therefore, indicate good possibilities for development of a technique for nondestructive evaluation of structural elements or production items of irregular shape.

Likewise, increases in the dielectric constant and loss tangent of Douglas-fir were both found to closely parallel increases in moisture content. They thus may be used for nondestructive measurements of moisture content. Related studies under way involve the effect of temperature on the electrical resistance and radio-frequency power loss of wood, vibration characteristics of hardboard as affected by temperature, moisture content, and composition, and dynamic strength of wood as related to its elastic properties.

In keeping with long-time FPL policy of assessing the properties of new and little-used species, *Eucalyptus saligna* grown on Hawaii plantations was evaluated for properties of greatest importance in structural uses. The wood was found to be quite similar to shagbark hickory except for its lower specific gravity and toughness. Hawaiian grown *Eucalyptus pilularis, Auracaria excelsa,* and *Albizia falcata* are being similarly evaluated, the latter also as a cabinet wood.

A recheck of properties of western hemlock established many years ago was made with wood samples from 15 trees in Oregon. The new data were essentially the same, so that no important changes were necessary in average properties.

Wood-Base Panel Materials

The vigorous expansion in use of building fiberboards and particle boards that has taken place in recent years has drawn attention to their physical and engineering properties. Establishment of reliable data on these properties is the object of an extensive research project at FPL, in part done cooperatively with the American Hardboard Association.

Engineering design values for flexure, compression, tension, and shear properties of hardboard are being studied with respect to the effects of relative humidity and moisture content. In general, equilibrium moisture content values for hardboard at any given condition from ovendry to soaked have been established at about 60 percent of those for wood. At the standard nominal moisture content of 12 percent for wood, for example, hardboards were found to average about 7 percent. It is now possible for industry to estimate equilibrium moisture content values for hardboard at any given relative humidity exposure or, alternatively, what the equilibrium moisture content for hardboard is at a given condition of exposure.

Changes in strength of hardboard with moisture content have also been established. On the average, strength is increased about 12 percent when the moisture content of the material is reduced from equilibrium with 64 percent relative humidity to equilibrium with 30 percent. If relative humidity is raised from 64 to 90 percent, conversely, the strength of hardboard is reduced about 22 percent. Some properties, of course, are affected more than others.

Severe earthquake shocks can probably be withstood by houses and similar buildings sheathed on one side of walls with hardboard properly applied. This was concluded from experiments on the racking resistance of standard wood-framed wall panels sheathed on both faces with ¼-inch tempered hardboard nailed or nail-glued in place. The panels were subjected to cyclic loading to obtain data on their damping, stiffness, and energy absorption properties, relating these data to shock-wave accelograms of the 1942 earthquake at El Centro, Calif., and assuming a dead load atop the panel of 15,000 pounds. For the poorest panel in the study, estimated deformation from quake forces was calculated to be 0.17 inch. In the static tests, however, deformations of at least 0.40 inch were required to produce any appreciable permanent distortion.

A major revision of the commercial standard for particle board was completed and transmitted to the Commodity Standards Division of the U.S. Department of Commerce, which circulated it to industry for acceptance. Industry comments were coordinated, and the standard made ready for issuance.

Properties of Full-Size Components

The widespread use of laminated structural members, trusses, and other building components, both in housing and heavy construction, has created a need for more precise determination of the strength properties of full-size elements used in these structural parts. Laminated beams, for example, undergo both compressive and tensile stresses when loaded in bending. Different elements of trusses, likewise, are stressed in compression or tension.

Heretofore, principal reliance for design criteria used to determine sizes, species, and qualities of lumber for these elements has been based on strength properties obtained by standard test procedures on small clear specimens of wood. The actual test values are reduced for estimated effects of

Technician George Paulson adjusts lateral supporting block against 2 by 4 to be loaded in compression with hydraulic jack after plank bolted to steel I-beam is lowered against face of piece.
M 124 767

knots, cross grain, and other natural characteristics for moisture content and service conditions, and by a factor of safety.

During 1964, FPL engineers developed methods of testing full-size framing lumber in tension and in compressive end loading with lateral restraint. Both methods yielded fresh insight into the actual effects of such strength-reducing natural characteristics as knots and cross grain.

The new method of test in tension was made possible by development of a unique type of grip. Heretofore, devices for gripping specimens at the ends

Apparatus used to evaluate full-size framing lumber for tensile strength utilizes new wedge-like end grips.
M 124 770

for application of tensile loads have generally resulted in some crushing of the wood or other weakening, so that failure occurred there before the full tensile strength of the specimen could be determined. The new grips have faces sloping inward toward the ends of the piece. They thus exert a wedgelike gripping action that does not produce localized crushing or stress concentration and premature failure. Excellent experimental data have been obtained on specimens 2 by 4 or 6 inches in cross section and up to 16 feet long.

The new method of testing dimension lumber in compression involves application of lateral restraint on all four faces of the specimen while under load. By thus preventing deflection, the specimen is kept straight while compressive force is applied. Good reproducibility of results has been obtained, and experimental verification of the method is continuing on other species and grades of 2-inch dimension lumber in lengths up to 16 feet.

Evaluations of full-scale members have also become more necessary in the past few years with the development of mechanical stress-grading machines in use at sawmills. These replace visual grading based on the appearance of the piece — that is, size and distribution of knots or other characteristics that affect strength and stiffness, which are strictly limited with respect to conventional grades of construction lumber.

Mechanical stress grading is not directly related to the size and distribution of these natural characteristics. The only criterion of quality is the strength and stiffness of the piece, as determined by loads and deflections too low to damage the material but large enough to provide a mathematical basis for determining acceptability for a given grade. Stress ratings of the various grades of a given species are consequently more critical, in a way, for machine-graded than for visually graded lumber. It therefore becomes important to determine as precisely as possible the relation of the low loads applied in machine grading to the full strength of the pieces being graded. This also requires methods of evaluating full-size structural lumber.

During 1965, an extensive study of southern pine construction lumber afforded opportunity to establish the relationship of small nondestructive loads and deflections like those applied by a grading machine to the actual strength and stiffness of the same full-size pieces. This work was done in cooperation with the Southern Pine Inspection Bureau, primarily to survey dimension lumber grades in connection with liberalized design criteria based on the load-sharing concept for conventional joists and rafters. Data obtained are being analyzed to determine the correctness of present load-sharing estimates.

A similar study was undertaken for the Federal

Housing Administration. For this work, machine-graded lumber was obtained from several retailers who had purchased it from western mills. Some 300 pieces of 2 by 4 intended for use in fabricated trussed rafters were visually graded and given standard evaluations for strength and stiffness in bending, compression, and tension. Thus the original machine grading is being checked out by visual grading and also by laboratory data on strength. Findings will guide FHA in reaching decisions on utilization of machine-graded lumber, thus far approved on an experimental basis.

Structural Laminated Members

Successful experiments with prestressed laminated beams, as described in the 1963 Annual Report, were followed with a long-time loading experiment to determine whether relaxing of prestress might result from a slowly developing kind of deformation called creep. The experiment was begun late in 1964. At year's end, there was no discernible evidence that creep was likely to be critical. The type of prestressed beam under evaluation is one in which steel cables are passed through holes on the lower half of the beam and stressed, so that a slight upward camber is produced in the beam.

Special design criteria were developed for tapered laminated beams — that is, beams of larger cross section in the center than at the ends, or larger at one end than the other. Such beams are used for special purposes, often for architectural effects. Design criteria were needed by designers and manufacturers of such members to assure efficient, safe structures. The FPL design criteria include considerations of both stress and deflection for straight wood beams of single and double taper. Analysis verified by experiment showed that the combined action of bending stress, shear stress, and vertical stress must be considered in designing beams, because these stresses can all be maximum at the same point in the beam. Charts were developed for rapid determination of correct beam dimensions based on deflection criteria.

A theory was developed that explains why ponding of water on flat roofs can sometimes result in collapse of the roof structure. Experimentally verified design criteria based on this theory showed that, unless loading caused by ponding of water is fully taken into account, even slight initial ponding can trigger a chain of deflections, each followed by additional ponding, that ultimately can overload the roof. Collapse occurs when, during such a series of additional loadings and deflections, the resisting forces in the roof beams never reach equilibrium with the loads imposed.

Highway Bridge Design

A theoretical analysis was completed of the lattice system of beams and stringers as used in bridges, floors, and roofs. Results of experiments on timber highway bridges, both in the Laboratory and on actual bridges on forest roads in the West and South, supported the validity of the analysis. The analysis is based on a displacement method utilizing slope-deflection expressions combined with matrix notation, and lends itself to relatively simple solution by computer.

Metal weights are piled on loading yokes by Lyle McConnell and Billy Bohannan for long-time loading of prestressed laminated beams to study fatigue characteristics. Bohannan is engineer in charge of study.
M 127 636

Experimental study of decks of conventional timber-stringer bridges indicated greater distribution of wheel loads than had been previously assumed. Recommendations have therefore been made for more liberal design load allowances.

Fastenings

New types of nails, staples, and other mechanical fastenings frequently are developed by industry, and often look promising for such uses as wood containers. In this category is a new nylon-coated staple which has shown exceptional resistance to withdrawal for at least a year and thus can be expected to hold better in containers placed in storage for long periods. A helically threaded nail showed similar ability to retain holding power over a long period of time.

Fastenings to be used in wood treated with fire-retardant chemicals should be chosen with corrosion resistance in mind, experiments clearly demonstrated. Common wire nails were found to develop greater withdrawal resistance in wood so treated than in untreated wood while exposed to high humidity. The gain was attributed to corrosion, which in its early stages could account for the gain. Continued corrosion would, of course, seriously weaken the nails. Bolted joint strengths were lower in dry treated wood than in dry untreated wood.

L. O. Anderson, left, and J. A. Liska, FPL research engineers, make notes on damage done to a wood frame house that had been torn from its foundation by an upthrust of the earthquake that struck Anchorage, Alaska, on Good Friday. The inspection was made 4 days after the quake struck southern Alaska. Liska is chief of the Laboratory's Division of Wood Engineering Research.

Housing Research

The disastrous Good Friday, 1964, earthquake in Alaska demonstrated the shock resistance capability of well-built wood houses. Immediately after the quake, two FPL structural research engineers inspected buildings struck by the full force of the quake at Anchorage. Light wood-frame buildings with walls fabricated to act as diaphragms withstood the shocks well and showed surprising resistance to ground subsidence and displacement. The importance of proper fastening of components to each other to insure that the structure would act as a unit was decidedly evident, the engineers reported.

An experimental two-story house built in 1938 of then-revolutionary stressed-skin panels and used as office space ever since underwent a final series of experiments to evaluate its structural condition before being dismantled. It was one of two houses built at the time. The other, a one-story, will continue its experimental existence, although it must be moved to another site on the Laboratory grounds.

The two houses are prototypes of a system of construction developed by FPL research engineers and since then widely adopted by the manufactured house industry. The unit panels are 4 by 8 or more feet in size, and vary in thickness depending on their use in floors, walls, or roofs. They consist of ply-

Engineer Thomas L. Wilkinson measures distortion of panel from experimental stressed-skin-panel house caused by racking force applied to upper right corner.
M 124 918

wood sheets nail-glued to light lumber framework. Their design is basically that of a box beam, and accordingly they can be built to carry predetermined loads, thus representing a marked advantage in house design.

The two-story house was subjected to a unique method of full-scale loading to determine its resistance to wind loads. An arrangement of wood beams across its facade permitted the application of forces simulating winds up to 125 miles per hour — a full-scale hurricane — by means of hydraulic winches. There was virtually no racking of the walls at right angles to the facade, nor was the structure noticeably raised from its foundation. The structural rigidity of the building after more than a quarter century of use was thus conclusively demonstrated—a convincing testimonial to the adequacy of the design concept.

Prototype structural elements for a new system of house wall and roof construction were evaluated. Racking resistance of braced and covered walls designed for 4-foot spacing of framework was found to be satisfactory. Roof trusses designed for 4-foot spacing had good strength but require some modification of fabricating techniques commonly used for trusses. A plastic-covered roof panel satisfactorily withstood 6 months of outdoor exposure.

Packaging

Glue skips and other variations that occur during manufacture of corrugated container board are mainly responsible for the considerable variability in compressive strength of the finished containers. These glue skips can be eliminated almost entirely, experiments in corrugated board production indicate. A portable radiation pyrometer that measures temperature of sheets moving through the corrugating and gluing machine helped establish optimum combining conditions. Moisture-content measurements and a tension-measuring device were also found useful in maintaining proper control of manufacturing conditions.

With completion of experiments described in the 1963 Annual Report, a performance specification was prepared on Fiberneer, a combination veneer and extensible kraft paper material for containers, and submitted to the cooperator on the development project, the Air Force. Strong interest in the material, which maintains high stacking strength under highly humid storage and shipping conditions, has been shown by industry.

Pallets

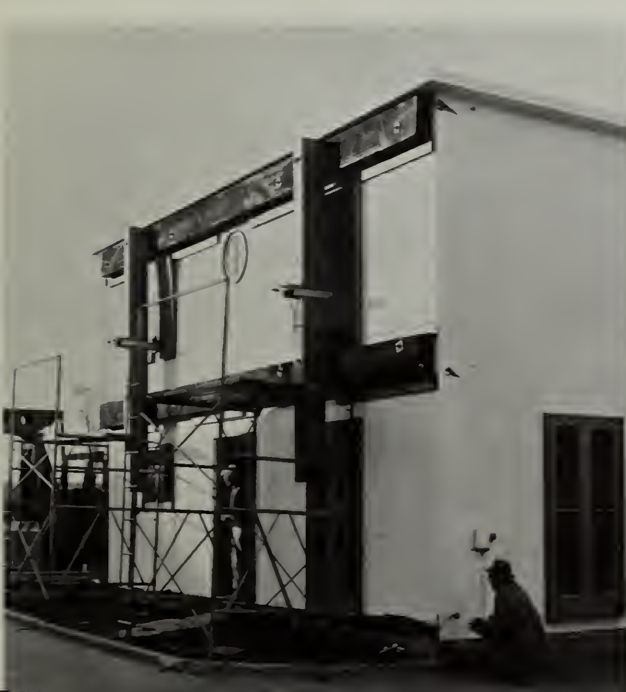
A new evaluation of plywood pallets was begun to ascertain the most suitable designs of these widely used platforms designed for mechanized handling of packaged goods, machinery, and other industrial and agricultural products. The evaluation was preceded by a survey of industry experience with these pallets intended to determine their shortcomings, if any. Survey results included:

1. Generally, plywood pallets are giving satisfactory service and are considered economical because of their durability.

2. Pallet damage during service consists of fraying along the deck edges, often caused by misguided forklifts, and bolthead pullthrough, especially when countersunk too deeply in the decking.

A comparative study of the suitability of various western species little used for pallets showed that, in overall pallet performance, red alder, black cottonwood, western hemlock, and ponderosa pine were better than Douglas-fir, but tanoak and western larch were less satisfactory.

Two massive horizontal and two vertical timbers comprised harness on face of this two-story experimental house subjected to simulated wind loads. Cables attached to both vertical timbers passed through upper windows to hydraulic winches, which applied load.
M 124 574



Vibrational force is applied by Packaging Engineer Thomas Heebink to plywood pallet loaded with concrete block.
M 128 279

SOLID WOOD PRODUCTS RESEARCH

The production and use of lumber, plywood, laminated structural members, particle board, and other solid wood products are controlled by two conditions: (1) the developing technology which industry utilizes to improve existing and devise new processes and techniques; and (2) the character of the available raw material. Both conditions must be considered when planning and carrying on research on solid wood products. Advances in technology spring largely from research findings. And research must deal realistically with available raw material, seeking knowledge that will open new and better ways of using it.

During 1964, FPL research in solid wood products was oriented to take increased recognition of the changing character of the Nation's forest resources. More attention was directed toward utilization of hardwoods, which Forest Service statistics have shown to be increasingly plentiful in Eastern forests, and on the lower grades of both hardwoods and softwoods. Attention was directed particularly toward finding ways to broaden the usefulness of low-grade hardwoods for such products as flooring and wall paneling, and toward adapting such new techniques as roll laminating for application of paper, plastic, and other types of overlay materials to surfaces of low-quality wood.

A new series of investigations of the effects of temperature, moisture, and other environmental factors on serviceability of wood, begun a few years ago, supplied information of broad usefulness to the wood industries.

Experiments with a rotary pressure bar in the rotary cutting of veneer, instead of the conventional fixed nosebar, significantly reduced the frequency and size of lathe checks — cracks which form as the veneer is cut.

Data essential for a better understanding of wood drying were obtained in a new basic study of the permeability of wood to water.

A planer head designed for the surfacing of dimension lumber yielded shavings much more suitable than conventional planer shavings for particle board and molded wood products. A technique for evaluating glue joints in laminated members reduced to a single 8-hour day a quality control procedure formerly requiring much longer.

The FPL 8-foot tunnel furnace method of evaluating surface flammability of wood products was accepted for research and development purposes by a subcommittee of the American Society for Testing and Materials and was in use at nine laboratories.

A house of many parts is this new exposure-site instrumentation structure designed by FPL engineers. Wall, floors, roof contain as many different experimental materials and building components as could be crowded in. Meteorologist Cassandra Steinkopf and Technologist Robert Hann, in charge of FPL environmental research, read thermometer registering maximum and minimum temperatures.
M 124 960

Environmental Effects on Wood

A major purpose of FPL research on the effects of environment on performance of wood products is to learn more about the moisture content of wood in use under various climatic conditions. Wood swells as it takes on moisture from its surroundings and shrinks as it gives off moisture, and these dimensional changes can affect product performance to a marked degree. More precise information about actual temperatures and other conditions to which wood is subjected from day to day is needed to design products properly for the environment in which they serve. Data gathering of this sort is a major task of FPL environmental research. Temperature readings, for example, may cover periods of a few minutes or many months.

In the first few years that this project has been under way, it has been necessary to concentrate on data-gathering techniques. Electronic instrumentation has been devised that automatically registers and records temperatures, moisture content variations and gradients, and electromagnetic radiation in the infrared and ultraviolet as well as the visible light wavelengths.

A ready means of determining the maximum surface temperatures to which a wood product will be exposed in any climate was devised. The method should prove of great use to industry in selecting suitably heat-resistant adhesives and paints or other finishes for a given climatic environment, as well as in product development work.

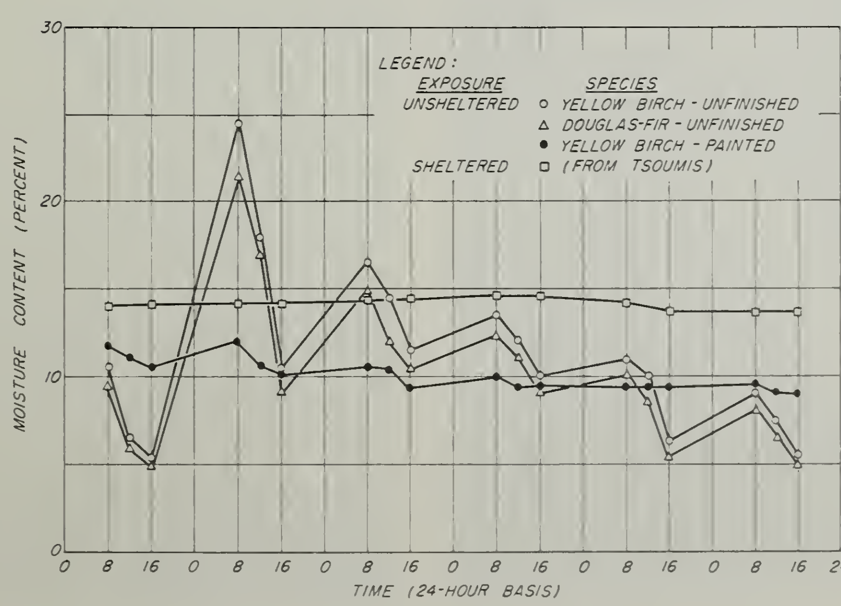
The method was evolved from a study of the relation of plywood roof sheathing temperatures to climatic factors. Results, coupled with meteorological theory, made it possible to relate the maximum surface temperature of a wood product used outdoors to its surface reflectivity, air temperature, and solar radiation. Reflectivity is easily measured, and Weather Bureau data on temperature and radiation can be used to calculate maximum surface temperatures for most locations in the United States.

Data on the heat reflection and emission properties of wood were obtained by infrared spectrophotometry in a study of the heating and cooling of exterior surfaces and related weather factors, such as dew formation. Infrared reflection can be used to measure surface temperatures, which indicate differences in moisture content. Industry is now evaluating this technique as the basis for a nondestructive quality-control test to check uniformity of dryness of veneer and lumber on the production line.

Evidence that paints and water repellents afford considerable protection to wood surfaces from the severe changes in moisture content that occur in unprotected surface zones of wood was furnished by data gathered on the daily fluctuations in moisture content which painted and unpainted plywood specimens underwent within a week when exposed outdoors.

Studies of how the speed of wind affects the surface temperature and moisture content of wood were conducted in a small wind tunnel. Results were in-

Painted yellow birch remained much more constant in surface moisture content than unpainted yellow birch and Douglas-fir in this 6-day period while exposed outdoors to rain, sun, and dew. The curve representing information from Tsoumis, published in Holz als Roh- und Werkstoff, Vol. 18, P. 421 (1960) is based on wood specimens exposed outdoors but protected from rain and sun.
M 124 730



Meteorologist Eugene Wengert adjusts wind-speed indicator in FPL wind tunnel used to study effects of air movement on moisture content of wood surface on floor of glass-enclosed tunnel.
M 128 300

terpreted in terms of low-velocity aerodynamic theory based on studies conducted elsewhere on wind movement over crops and water and the flow of liquid in pipes. The findings make it possible to predict mathematically the most suitable air velocities for air drying, kiln drying, and jet drying. The results also have application to studies of heat and moisture transfer in buildings, such as occurs through heat loss in winter and moisture vapor passage through walls.

A major forward step in environmental studies at the Madison exposure site was taken during 1964 with construction of a small experimental building. This structure was designed for the particular purpose; for example, its walls were built with different types of materials, including insulation, vapor barriers, and covering materials. This makes it possible to compare different materials and constructions under conditions as nearly alike as possible. Other unique structural features are experimental shingles and a deck floored with lumber treated to remove thiamine, a vitamin essential for growth of decay fungi.

Instrumentation installed in the building is designed to record temperature and moisture content of exterior and interior surfaces as well as within the wall panels themselves. It is thus being rigorously tried out here before being adapted for similar use at other locations.

This structure is also being used for exploratory research on a method of heating buildings that is called radiant comfort control. Conventional methods utilize heated air. Radiant comfort control is based on the warming effects of infrared radiation on the human body. Infrared rays produced by a lamp, for example, are reflected from walls and ceilings coated with a special paint formulated for the purpose. Human beings warmed with these rays are comfortable at air and wall surface temperatures considerably lower than those in conventionally heated rooms, and thus fuel costs are markedly lowered.

FPL studies of radiant comfort control with infrared radiation are being conducted primarily to establish its effects on moisture content of wood structural framing and wood surfaces, such as floor-

Carpenters Dode Wergin and Ed Siebert lay plywood facing of 8- by 8-foot wall panel on section without vapor barrier but heavily insulated for moisture-temperature experiments. Panel was installed in wall of new FPL structure for environmental experiments.
M 126 380

ing and wall paneling. Although the principle of radiant comfort control is not new, the method has not been widely tried. Obviously, houses so heated would not need to be nearly so heavily insulated as conventionally heated houses. The markedly lower air temperatures would substantially affect moisture content levels of wood in houses designed for radiant temperature control. And finally, structural design would in all probability be altered.

A few preliminary data obtained late in 1964 indicate that air temperatures up to 10° F. lower than those associated with conventional heating do not materially affect human comfort. For example, a person accustomed to air heated to 74° F. with a conventional furnace could be comfortable at 64° F. with infrared radiation of adequate density.

Rotary-Cut Slicewood

For some years, FPL has conducted experiments with a veneer slicer for the cutting of material in thicknesses approaching thin lumber — up to one-half inch. Traditionally, the term veneer is limited to material up to $\frac{1}{4}$ inch thick. Since lumber is by definition a sawn product, the term Slicewood has been adopted by FPL to designate material thicker than $\frac{1}{4}$ inch produced by knife-cutting.

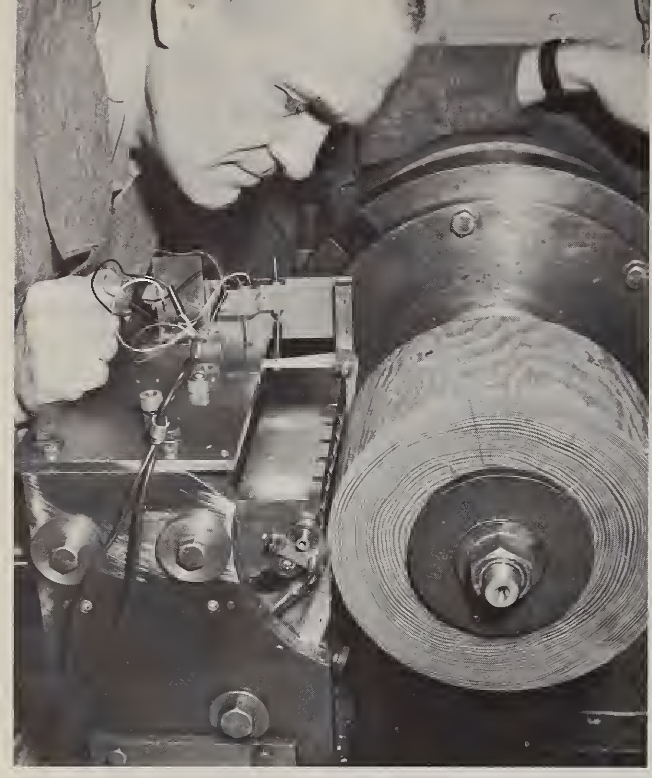
During 1964, studies of Slicewood production with a veneer slicer consisted chiefly of design development of a new and more versatile experimental machine. A study of the benefits of precompressing flitches to eliminate knife checks in sliced veneer was continued.

Meanwhile, however, some experimental work was done on the cutting of $\frac{3}{8}$-inch material on the rotary lathe, a much more widely used veneer-cutting machine in softwood mills. These experiments were conducted with a rotating roller pressure bar instead of the conventional stationary bar to apply pressure to the veneer bolt in the area where it strikes the cutting blade.

Results showed that, the greater the pressure applied with the roller bar, the smaller the knife checks, or breaks, that develop in veneer as it is cut from the bolt. Pressure was increased by inserting progressively thicker metal shims between the bolt and the roller bar. The thicker the shims, the smaller the checks.

The initial experiment was made on unheated

Meteorologist Cassandra Steinkopf checks wiring of net radiometer that measures difference between infrared radiation passing to and reflected from wall. Wiring conducts signals to system outside room that automatically punches data on computer cards. Wall is covered with finish material designed for high reflectance of infrared heat waves in study of radiant comfort control method of heating.



Technologist John Lutz studies action of roller pressure bar on veneer being cut on experimental lathe from southern pine bolt.
M 128 136

yellow-poplar. The noteworthy improvement in veneer quality, as reflected by size and frequency of lathe checks, prompted development of more sophisticated experimental equipment, including instrumentation to measure pressure and thus gain valuable data for evaluating results with various species and drawing up recommendations for commercial use techniques if results warrant.

New Dimension Planing Concept

A new approach to the planing of softwood dimension lumber has resulted in the production of flakes much more suitable for use in particle board than conventional planer shavings or pulp chips. Particle boards made from the new-type flakes were up to 50 percent stronger and more stable in length, width, and thickness.

Key to the new concept is a disk or ring planer head with cutting knives fixed to its sides. It thus cuts across a face or edge of the 2-inch stock passing through the machine, rather than along the length of the piece like a conventional planer. Flakes produced are quite uniform in length and thickness, rather than haphazard in shape and curled. The cutter does not produce so smooth a surface as does a conventional planer head, but highly acceptable surfaces can be obtained with a second cutter that has an abrasive action producing fine particles probably utilizable for boards and molded products.

An estimated 10 million tons of planer shavings are produced in western dimension mills yearly and mainly consigned to power generation or scrap burners. Their poor shape is chiefly responsible for their low value, about $3 a ton, for pulp or particle board. It is estimated that the uniform flake-like flat shavings produced with the new FPL cutterhead would be worth $6 a ton for pulp or at least $15 a ton for particle board. The fine, hair-like fibers removed by abrasive planing produced in the second step of the new planing method would also probably be worth up to $15 a ton. Properties of flat pressed products made from wood particles are influenced by the amount of compression given them, the molding temperature used, and the manner in which pressure is applied. Particle geometry has an important influence on dimensional stability and strength; stick-like particles produce boards with better static bending strength and linear stability than do cube-shaped particles. While both of these particles exhibit poor flow characteristics as compared with conventional molding powders when mixed with powdered resin, they do not react to compression the same way. A flow test was developed, based upon the compression of a cone-shaped mat, to evaluate this reaction.

Research on particle board processing will be greatly facilitated in 1965 by acquisition of a new press specially designed for investigation of processing variables, such as temperature, pressure, types and application of bonding resins, form and generation of particles, and effects of fire retardants and preservatives on board properties and performance characteristics. Much of this and other process development work will be aimed at finding uses for hardwoods.

Wood Drying

The rate at which water can pass through wood, and the conditions that affect passage, are fundamental aspects of wood drying. In the broader sense, movement of any liquid through wood and the conditions affecting such movement have fundamental significance for such treatments as preservation against decay, insect protection, and fireproofing. FPL research on the permeability of wood to water, therefore, has wide applicability.

During 1964, research techniques for determining true permeability were refined and noteworthy basic findings made. It has long been known that water occurs in wood under two distinct sets of conditions. The cell cavities of green wood contain liquid water or so-called "free" water; but the cell walls attract and hold "adsorbed" water, which is responsible for the swollen state of green wood. In drying, wood first loses the free water, which may be present in much larger amounts than the adsorbed water. Only after much of the free water has been removed does the adsorbed water begin to leave and shrinkage start.

Better methods of removing these great quantities of free water from wood are contingent upon better understanding of the movement of liquid

water through wood—that is, the permeability of the wood. Better techniques devised for study of permeability are beginning to yield the kind of data that are needed.

Experiments with green eastern hemlock showed that the sapwood of this species is about 100 times more permeable to water than is the heartwood. During drying, the permeability of sapwood decreases considerably to a value only a few times greater than that of heartwood. That the new techniques measure true permeability of sapwood is demonstrated by the fact that, after the first reversal of water movement direction, permeability values obtained are unaffected by time, pressure, or direction of flow. A key factor in this technique, it was found, is the use of highly purified water. Even slight impurities, such as dissolved gases, affected the reproducibility of results. Heartwood permeability values, though affected by time, pressure, and flow direction, were also reproducible, hence useful at least in a comparative sense.

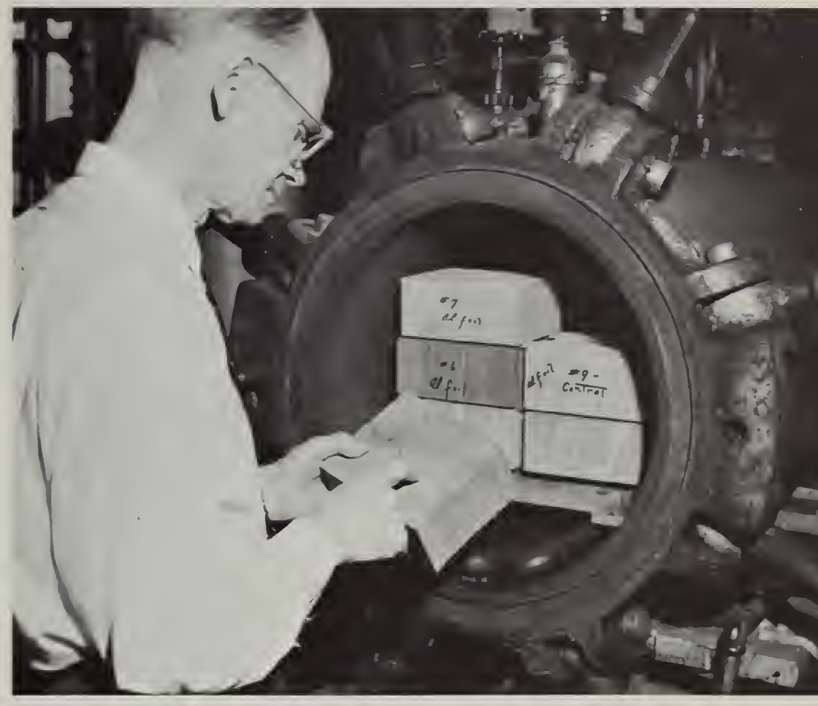
More extensive research was undertaken on drying of southern pine Slicewood intermediate in thickness between veneer and lumber. For $\frac{3}{8}$-inch material, a screen-press dryer and jet and conventional veneer dryers completed the drying to 8 percent moisture content in minutes, while dry kilns accomplished it in as little as 7 hours. The presence of knife checks in sliced material resulted in a 10 percent advantage in drying rate over material sawn oversize and surfaced to the same thickness. The research included determination of drying rates, shrinkage, and dried-wood quality for different thicknesses and temperatures by the several methods employed.

Glue Joint Quality Control

By using a new method of evaluating glue joint durability, producers of laminated structural members can maintain quality control much more simply and effectively than with older procedures, which are much slower. The FPL technique reduces to a single 8-hour workday an evaluation that formerly required weeks.

The procedure consists of rapidly impregnating production specimens with water in a cylinder by alternating vacuum and pressure to cause maximum swelling of the wood, then briefly steaming them at atmospheric pressure. The treatment breaks downs and destroys adhesives known to be nondurable. Those of intermediate durability show intermediate amounts of failure. The most durable adhesives show no signs of failure.

While developed primarily for use in differentiating durable from nondurable adhesives, the technique also gives manufacturers the quickest way yet to check periodically the quality of production.

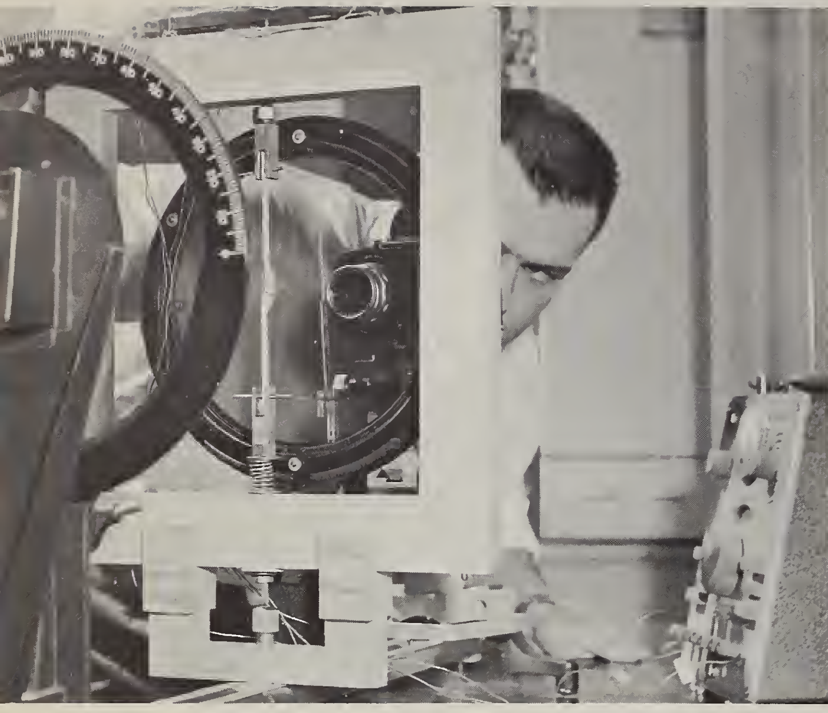


M. L. Selbo, chemical engineer in charge of FPL laminating research, examines a specimen used in new FPL 8-hour quality control technique to evaluate durability of adhesive joints.
M 124 932

Glues and Glued Products

The increasing industrial importance of glues and bonded joints in structures that carry loads has created need for better knowledge of the chemical and physical properties of adhesives and the bonds they form with wood. FPL scientists are seeking to broaden such knowledge by determining the properties of adhesive films and relating these properties to those of adhesives bonded to wood as in a typical glue joint. Ultimately it is hoped not only to establish such relationships, but to learn whether any reactions, chemical or physical, develop between wood and adhesive during the gluing operation or afterward, and whether these reactions have beneficial or harmful effects on bond strength and durability.

Free films of conventional and experimental adhesives have been prepared and their behavior studied under tensile load. The amount of strain (elongation) that the film undergoes for a given amount of stress at a specific rate of loading is a measure of its modulus of elasticity, an indicator of stiffness. The stress-strain behavior of a free film of one of the experimental materials was compared with that of the same adhesive functioning as a film in a joint. The free film was about 20 percent higher in apparent modulus of elasticity than the film in the joint. In the same series of experiments one free adhesive film was also evaluated for creep (strain under long-time loading).



Photoelastic polariscope is used by Dieter Kutscha, physical chemist, to study stress distribution induced by tensile load in lap joint made with a birefringent resin adhesive. Light-polarizing filters reveal stress-distribution patterns recorded with camera.
M 124 963

While these findings are preliminary in nature, they do indicate that useful information about the mechanical properties of adhesives may be gained from studies of the behavior of free films under load. Ultimately such information will help us to better interpret the data obtained from more conventional strength tests and should provide guidance for the choice of adhesives on the basis of mechanical behavior to yield specific desired strength and deformation behavior of wood joints.

An example of how knowledge of adhesive properties can be useful in structural planning was the design and evaluation of a special gusset-type hinged arch. A key factor in the design was an adhesive of known shear behavior in modulus of rigidity, creep, and stress relaxation. With this knowledge, it was possible to design large plywood gusset-plate joints to specified requirements of movement and rotational behavior. For a given applied moment, the joint would rotate predictably. The design was verified within 5 percent by behavior under load of a full-scale experimental hinged arch. The design also made possible more equal sharing of load throughout the frame by the structural members.

One of the more difficult problems associated with the gluing of fire-retardant-treated wood involves incompatability between the adhesive and the retardant chemical. In the 1963 Annual Report, research on this problem was described. Subsequent investigation has confirmed that ammonium salts used as retardants react with free formaldehyde in the curing agent in resorcinol-formaldehyde glue to cause premature gelation of the glue and increase its acidity, which interferes with curing. There is some evidence that fire retardants containing zinc chloride and boric acid also interfere with the true gelation rate and possibly the curing reactions of a resorcinol adhesive.

Plans for future research include installation of a roller press in 1965 to expedite studies of continuous bonding techniques for applying various types of overlay materials to lumber, plywood, and wood-base panel products.

Wood Finishing Research

Research on the effects of ultraviolet radiation on thin veneers suggests that certain treatments may have promise for protecting wood from photochemical degradation. This research is being conducted in cooperation with the National Lumber Manufacturers Association and the National Paint, Varnish, and Lacquer Manufacturers Association, with the object of learning the exact chemical reactions that occur. As noted in the 1963 Annual Report, ultraviolet rays cause various chemical products to form from wood. Among such products are carbon monoxide, carbon dioxide, hydrogen, formaldehyde, and methanol. In subsequent work, veneers have been shown to lose weight significantly as a result of this degradation, largely oxidative in nature.

Chemical breakdown was reduced by chemical modification of wood with urea. This suggests that it may be possible to increase wood's resistance to effects of irradiation by chemical treatments. Such treatments would be especially helpful in prolonging the service life of clear finishes on wood exposed outdoors, such as house siding and doors.

Fire Resistance of Wood

The rate at which wood chars under fire conditions is a key factor in estimating the fire resistance of a wood structure, especially one built of wood beams, columns, arches, or other large framing members. Char acts as an insulator that slows burning. FPL research on char formation was again conducted in 1964 in cooperation with the National Lumber Manufacturers Association, and data were obtained on southern pine and white oak that are comparable to those given in the 1963 Annual Report for Douglas-fir. The object of the work is to develop criteria for designing wood structures with predetermined levels of fire endurance.

In these studies, time-temperature conditions prescribed in Designation E 119 of the American Society for Testing and Materials were used together with other conditions. An empirical equation was developed for calculating depth of char in Doug-

las-fir on the basis of known specific gravity and moisture content.

A mathematical model was derived that relates temperature rise and char formation to thermal diffusivity, density, and specific heat properties. With this model it was possible to predict thermal diffusivity of the three species under study, on the basis of the fire penetration data obtained experimentally.

The FPL 8-foot tunnel furnace method of evaluating the surface flammability of wood products is being considered for adoption by the American Society for Testing and Materials. It is now in use by nine laboratories. To determine how well results correlate, surface flammability of 14 materials was measured at FPL and three other laboratories with the method. There was good correlation of flame spread index values, but smoke and heat contribution values were variable.

Flammability and smoke development of several decorative and fire-retardant paints and several fire-retardant impregnants were evaluated by the FPL tunnel furnace method. Ammonium phosphate and zinc chloride were especially effective in reducing flammability of wood but developed more smoke than did less effective salts.

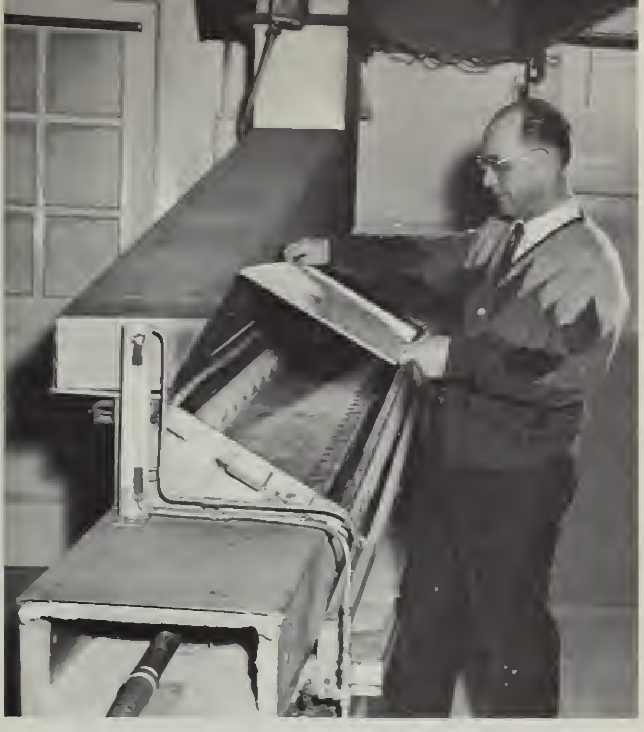
In a basic study of how the flaming and glowing characteristics of wood are reduced by fire-retardant salts, the weight and thermal changes sustained by wood, alphacellulose, and lignin exposed to constant temperatures or constant rate of heating were precisely determined in inert atmospheres and oxygen. Heating in an inert gas causes pyrolytic decomposition. Oxygen atmospheres, of course, permit normal burning.

Lignin began to pyrolyze at a slightly lower temperature than cellulose. Cellulose decomposition, however, was a rapid exothermic reaction occurring between 280° and 350° C., while lignin decomposed much more slowly, the reaction being less than half complete at 420° C. Most of the effective fire-retardant salts lowered the temperature at which wood and cellulose pyrolysis began, decreasing the formation of flammable tar and increasing the residual char weight at 350° C. There was practically no retardant effect, however, on the decomposition of the lignin.

In oxygen, flaming was due mainly to the decomposition of the cellulose, while glowing was sustained by the lignin. Effects of the different salts were varied, but in general they reduced the amount of heat released by the flaming. Many salt-treated specimens, however, developed more heat during the glowing reaction than did untreated controls, and sometimes there was even an intermediate exothermic reaction.

Decay Prevention

A research project older than the Forest Products Laboratory — begun by the Forest Service in 1908 — was brought up to date in 1964 with revision of a widely known FPL publication, entitled "Service Records on Treated and Untreated Fence Posts," and published as Forest Service Research Note FPL-068. Some 100 species of woods used for fence posts, 12 methods of treatment, and 80 preservatives are included in the latest edition. Detailed results of some 860 separate installations are given. Over the years, posts have been installed in the ground of 26 States from Connecticut to Hawaii.



Chemical Engineer Herbert W. Eickner places a specimen of plywood in the FPL 8-foot tunnel furnace devised to measure rate of flame advance from near to far end of specimen under controlled conditions of temperature and time.
M 124 935

Main purpose of these installations is to reveal which woods perform best with or without preservative treatment and which preservatives and treating methods are most effective in prolonging service life, mostly of round posts. Treatments compared range from brush application to pressure methods and include cold soaking, double diffusion, end diffusion, hot-and-cold bath, and steeping. Summaries of the effectiveness of each treatment are included in the report. Pressure treatment has generally provided the best protection to posts. End diffusion on green unpeeled posts has performed somewhat better than expected, extending the service life of posts 10 to 15 years over that of untreated posts, except for posts of several hardwoods under severe conditions in Mississippi. Double diffusion on carefully selected material is showing up as one of the most effective of the nonpressure methods for treating green, round posts. The hot-and-cold bath is the most effective nonpressure method for treating seasoned posts.

In the double diffusion method, developed at

FPL, copper sulfate is generally the first chemical applied. Second chemicals used have included sodium arsenate, sodium chromate, disodium phosphate, sodium fluoride, and borax-boric acid. Once diffused into the wood, the chemicals react with each other to form a water-insoluble compound.

During 1964, posts of ponderosa pine, red pine, lodgepole pine, Engelmann spruce, redwood, Inland-type Douglas-fir, baldcypress, and birch were treated by this process. The western species were installed on the Olympia, Wash., exposure site, the birch and red pine at a site near St. Paul, Minn., and the baldcypress on the Harrison Experimental Forest exposure site near Saucier, Miss. Results with the Engelmann spruce and Inland-type Douglas-fir are of special interest, because these species seem to treat quite well by double diffusion although they are difficult to treat by pressure.

Examination of piles removed from piers of the San Francisco-Oakland Bay bridge revealed serious shipworm damage in below-water sections that had been cut (dapped) to provde flat surfaces for attachment of bracing timbers. Dapping and bolt holes had exposed untreated interior wood of the creosoted 90-foot Douglas-fir piles, which were otherwise in good condition 28 years after installation.

Fundamentals of the Decay Process

Better understanding of how fungi cause wood to decay was obtained through microscopical studies of changes induced in a hardwood and a softwood by brown-rot and white-rot fungi. Findings were in accord with results of chemical studies of the fundamental character and process of decay. The information is expected to prove useful in finding improved means of protecting wood from fungus attack. Among significant microscopical observations were:

1. Decay of the cell wall does not depend on direct contact by the attacking fungus, but proceeds largely through enzymes secreted by the fungus, which can act upon the cell at a distance from the fungus.

2. White-rot fungi progress through the cell wall layer by layer, but brown-rot fungi can infect more than one layer simultaneously.

3. The amount of lignin in the cell wall apparently is a large factor in providing resistance to rot, the more heavily lignified walls of some types of cells having greater resistance.

Differences were observed in cell-wall decomposition produced in the hardwood and the softwood by the same fungus. These differences indicate that there are thus-far-unrecognized chemical or physical differences in the microstructure of hardwoods and softwoods.

During 1964, a study was begun of chemical and biological deterioration of pulp chips stored outdoors at a mill in Maine. The work is being done in cooperation with the Northeastern Forest Experiment Station. Biological aspects include evaluation of specific gravity losses, characteristics of discolorations, identification of the fungi or other microorganisms involved, and investigation of the physiology and destructive capacity of the organisms. Chemical aspects of this investigation are covered in the section of this Annual Report entitled "Wood Chemistry Research."

This insecticide-treated fiberboard was chewed by termites lured by attractant consisting of decayed block of wood.
M 127 770

Termite Attractant Bait

Field experiments in Wisconsin with a termite bait coupled with an insecticide showed promise of providing a new effective means of controlling and exterminating termite infestations. The "vehicle" for the insecticide is a few sheets of corrugated fiberboard like that widely used for shipping boxes. The fiberboard is placed a few inches beneath the surface of the ground, directly above a cube of wood partially decayed with a fungus known to produce the attractant.

The field experiments provided encouraging evidence that the lure works. Termites found the bait and ate the insecticide-treated fiberboard. It has not yet been possible, however, to gain clear-cut evidence of actual decimation of termite colonies.

It is planned to extend the field experiments in 1965 to the FPL exposure site near Saucier, Miss., where termite infestations are common.

WOOD QUALITY RESEARCH

Completion of a major segment of the nationwide Forest Service wood density survey of standing timber — the entire 11-State Western survey — highlighted FPL research in wood quality during 1964. Results were detailed in a preliminary report that went to all interested agencies — industry, governmental, and educational — for comment. The report was hailed as a milestone in forestry and in industrial utilization of timber.

A companion report for the southern pine region was in preparation at year's end.

Together these reports will constitute a quality catalog of most of the major softwood commercial species in the United States. By far the most complete information on the specific gravity of forests anywhere in the world will thus be available as guides to the lumber, plywood, pulpwood, and related forest-based industries in planning utilization of timber. Likewise, forest owners and managers will have much more reliable information on wood quality as measured by the known relationship of specific gravity to strength and related properties and pulp fiber content.

Among other significant advances in wood quality research during 1964 were a new sawing method specifically designed for milling southern pine logs into lumber more efficiently and profitably; a discovery that cambium cell growth in ash and aspen is dependent on availability of a chemical constituent known as myo-inositol — a finding that may lead to discovery of the role of this cyclitol in all forms of growth, animal as well as plant; and new photographic evidence of the true microstructure of wood fibers.

Density Survey Findings

The preliminary report on the western density survey gives detailed findings on one hardwood and eight softwoods — all recommended as priority species by the industry groups that helped support the work. Some 20 other species had also been sampled by Forest Service crews of the Pacific Northwest, Pacific Southwest, Intermountain, and Rocky Mountain Forest Experiment Stations, and data on these will be published as computer analyses become available. Details of the sampling procedures and related information have been published in previous Annual Reports.

The species covered in the preliminary western report are Douglas-fir, white, California red, grand, noble, and Pacific silver fir, western hemlock, western larch, and black cottonwood. Of these, the most widely distributed species throughout the western States is Douglas-fir. In the course of the sampling, increment cores were taken from 9,133 living Douglas-fir trees. The mean specific gravity for the entire range of growth, as established by core determinations, is 0.45, but the range is from 0.33 to 0.59.

While in general the specific gravity determinations confirm earlier values published in the FPL Wood Handbook, much new light is thrown on silvicultural and utilization problems of long standing. For example, only in the four-State "interior south" area comprised of Colorado, Utah, Arizona, and New Mexico was mean specific gravity consistently lower than in the rest of the region. The mean value was 0.43 and the range 0.33 to 0.55. But even this mean was considerably higher than the average for the region previously recognized and published in the Wood Handbook, 0.40. Likewise, for the area designated "interior north" and comprised of Montana, Wyoming, Idaho, and Oregon and Washington east of the Cascades, the survey mean of 0.45 was appreciably higher than the Wood Handbook average of 0.41.

The most significant difference between the new survey data and older published values, however, was developed in the data for western hemlock. The survey mean for this species is 0.42 — appreciably higher than the older average of 0.38. Also significantly higher were Pacific silver fir with a survey mean of 0.39 as against the old average of 0.35, and white and noble fir, with a mean of 0.37 and a published average of 0.35. Down a point were grand and California red fir, both with a survey mean of 0.36 and a published average of 0.37. Western larch dropped the most with a mean of 0.48 against a published average of 0.51.

The data, coupled with strength analyses based on them and discussed under Wood Engineering Research, are expected to find industry application in the determination of new design stress ratings for use by engineers, architects, and builders in construction with lumber, plywood, laminated structural members, and poles and piling.

Information of interest to foresters and timber owners and managers was also released for the nine species in the preliminary report. These data relate specific gravity to such growth factors as latitude, longitude, and elevation of the growth site, and to age, diameter at breast height, tree volume, growth rate, and certain other growth variables.

For the species of widest distribution, Douglas-fir, no such geographic relationships as those established for the southern pines (see Annual Reports for 1961 and 1962) were found. This is believed due, in part at least, to the tremendous localized

variations in site and growth factors caused by mountainous terrain. The pattern of specific gravity variation over the species range is therefore a patchwork.

Even when statistical analysis was confined to data for samples obtained west of the Cascades for coast-type Douglas-fir, only a minor portion of the total variation in specific gravity can be accounted for by such variables as latitude, elevation, tree age, tree diameter, and tree volume. A positive relationship between specific gravity and age was found for trees in age groups up to 35 years. There was little increase in specific gravity in mature trees.

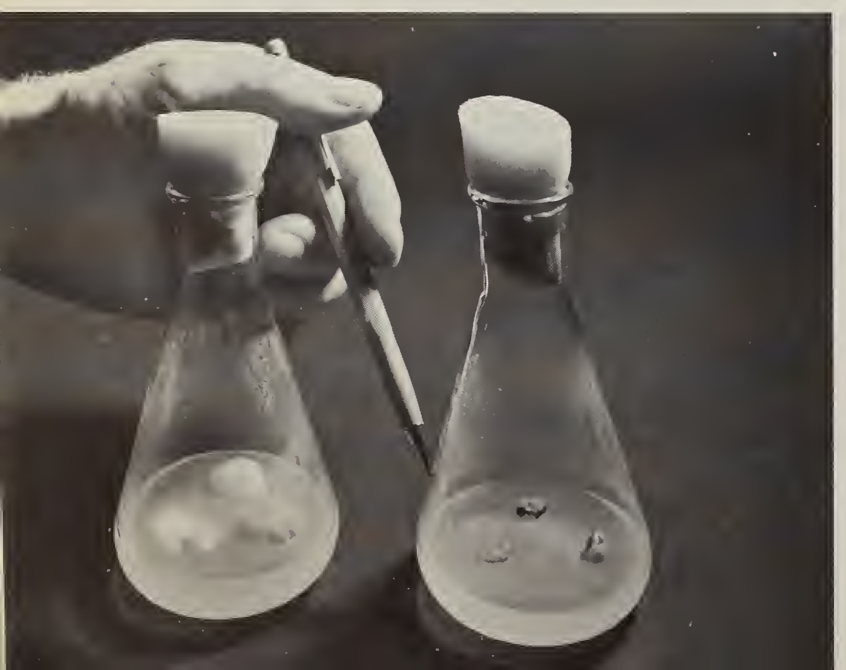
Some trend was also apparent, with age taken into consideration, toward declining specific gravity with increasing elevation. This effect appears strongest in mature stands of timber. The shorter, wetter, cooler growing seasons at the higher elevations appear to favor growth of wood that is less dense than that growing at lower elevations. Since most Douglas-fir logging takes place below the 3,000-foot level, however, the practical significance of this finding is open to doubt.

To obtain a better understanding of the causes of specific gravity variation in Douglas-fir, further studies are planned that will take into account such factors as soil, nutrient levels, microclimate, and refined measurements of anatomical characteristics.

Physiology of Growth

Discovery of the unique role of the cyclitol myo-inositol in growth of ash and aspen cambium tissue was an offshoot of a new project involving determination of essential and most favorable nutrient requirements for growth. Aims of the project were covered in the 1963 Annual Report. Since then, work on the initial phase of the project — development of suitable isolation and sterilization techniques for growing cambial tissues in the Laboratory under rigidly controlled conditions — has been advanced to the stage where effective techniques are in use.

Nutrients with (left) and without myo-inositol show effect of this factor on cambium cell growth.
M 128 313



Phase 2 of the project calls for development of essential and optimal nutrient requirements for cambial cell growth. These have been completed for ash and are under development for oak and aspen in cooperation with the University of Wisconsin.

The absolute necessity that myo-inositol be present in nutrient media for the cultures of ash and aspen has been clearly established. That this chemical constituent has a central role in the metabolism of growth is indicated by this need and by the effectiveness of the chemical at low hormonal-type levels.

These cyclitols occur widely in plants and animals, but their essential role in maintaining and possibly controlling growth processes is not known. The discovery of the unique requirement of these woods for myo-inositol to promote cell growth, therefore, offers opportunity to study its function in wood growth as an indicator of the role of cyclitols generally.

Experiments to date indicate that there is a marked degree of specificity for certain cyclitol molecules in promoting and maintaining cell growth in cambium. Further studies with radioactive myo-inositol are planned to trace the chemical and determine the exact location it assumes within the cell by observations with the electron microscope. Thereby it is hoped to learn more about the true role of these cyclitols generally in the physiology of organic matter.

Wood Structure-Strength Relations

New statistical evidence of the true effect of certain structural characteristics of wood fibers on strength was obtained in research relating intrinsic strength to the bundles of threadlike fibrils that comprise much of the fiber wall. The position of these fibers — that is, the angle they assume to the lengthwise fiber axis — has long been known to exert a pronounced influence on wood strength. Exact determination of this effect has now been statistically evaluated in loblolly pines 30 years old and of widely differing growth rates as recorded in their annual growth rings.

Simple regression analyses of strength and stiffness data showed that nearly 45 percent of the total variations are associated with variation in fibril angles. By comparison, 30 percent of the total variation is attributed to specific gravity. Together, specific gravity and fibril angle account for 85 percent of the strength and stiffness variation.

Studies of how fibril angle varies with position of the fiber in the tree show that fibril angle is greatest near the top and least near the base, ranging from about 25 to 10 degrees over this height span. Other studies show decreasing fibril angle with increasing cell wall thickness, fiber length, age in years from the pith, and percentage of summerwood

Spruce after treatment with periodate to remove cellulosic constituents of cell. Lignin remaining in torus shows it extending crescent-shaped across pit aperture. Magnification approximately 8,000X.

in the annual ring.

Fine Wood Structure

The long, tapered, tubelike tracheid cells of softwoods are characterized by openings in the cell walls called bordered pits, through which water and other liquids pass from fiber to fiber. The microscopic structure of these pits is important in treatments with preservatives, fire retardants, and other chemicals. Hence, knowledge of pit structure is vital to such processes.

Recently disagreement has risen among investigators as to the nature of the torus, which appears under the microscope to be a thick membrane extending across the pit opening. Some dispute its existence, contending that what appears to be an integral membrane structure is merely a heavily condensed ring of residual cellulose microfibrils deposited as water leaves the cell walls during drying of wood.

Recently, electrongraphs of the torus structure have shown that, after all cellulose has been removed by treatment of the wood with hydrofluoric acid or periodate, a torus-like membrane consisting entirely of lignin remains in the pit opening. These support and confirm earlier evidence, obtained with light microscopes, of a torus in green wood. Furthur electron microscope studies of untreated loblolly pine have shown that bundles of microfibrils form, usually in the fully grown tracheid, around circular fields that develop into a pit; and that in the center of the pit the microfibrils form a smaller circular field that becomes the torus. The microfibrils in the zone outside the torus, along with some of those in the torus, are drawn into a radiating bundle that becomes the pit membrane.

Pictorial evidence gained with the electron microscope thus clearly establishes a growth process that takes place in the tracheids to form the pit membrane and torus.

Wood Identification Service

The free public wood identification service furnished by FPL had another year of booming business. Requests for identification received from non-Forest Service sources were up substantially from 627 to 732. Requests from within the Forest Service also went up, from 110 to 128. Among materials submitted for identification were wood flour, charcoal, Pleistocene (glacial period) wood, petrified wood, archeological specimens, and many common industrial materials — the latter usually involved in disagreements as to species.

Species identification of American elms — that is, as between rock, American, and slippery elm — became possible from the wood alone with the discovery that water extracts of the three species differ as to turbidity and fluorescence under ultraviolet light.

The wood collection built up over the years and constantly used for identification purposes also grew during the year, and now numbers 22,092 positively identified specimens.

Hand Tool for Field Compressive Tests

A pliers-like instrument for testing wood nondestructively in compression was devised in response

Core compression test instrument.
M 126 909

to a manufacturer's inquiry for a quick means of testing wood as a basis for keeping trees or logs deficient in elastic strength out of the production line.

A slim cylindrical core is cut from the inspected log or tree with an increment borer. This core is placed in the jaws of the instrument, and pressure is applied by squeezing the handles together. A dial gage attached to one handle indicates the change in the gap between the jaws as a measure of the compression undergone by the core. The amount of force applied is determined by the extent to which one of the handles, part of which is a spring steel rod, is deflected with respect to an index plate. The force thus measured is proportional to the force applied to the core. By relating this force to the known bearing area of the jaws, the stress applied to the core is determined. This unit stress, when related to the amount of compression produced on the core, yields an index of the compressive elasticity of the wood parallel to the grain.

Southern Pine Stud Warp Reduced

That improved sawing methods can substantially reduce the amount of warp developing in 2 by 4 studs cut from loblolly pine was amply demonstrated by final results of experiments on logs obtained from the Hitchiti Experimental Forest in Georgia. Warp, of course, seriously reduces the grade of this type of framing lumber, which is widely used in walls of houses and other light construction.

An FPL improved sawing method described in the 1963 Annual Report proved to be 47 percent better in production of No. 1 and better studs from butt logs than the conventional method of sawing widely practiced throughout the South. Key to the improved method of sawing is the positioning of the logs so that proper recognition is made of log taper and cross sectional eccentricity. The weak pith wood is confined to a single wedge-shaped piece from the central area of the log, which is discarded as residue. Pith, or "juvenile," wood shrinks and swells longitudinally much more than mature wood, hence warps studs out of shape if present in unbalanced proportions along with mature wood.

In upper logs the problem of warp was found to be much less severe for all methods of sawing included in the study, but even with these logs the FPL method produced 7 percent more No. 1 studs than the conventional method.

In terms of southern pine lumber prices f.o.b. mill, logs sawn by the FPL method from butt logs yielded lumber worth about $10.50 more per thousand board feet than the conventional method. On a daily production of 40,000 to 100,000 board feet a day, this would mean an additional daily profit potential of $50 to $500 on lumber depending on the mix of butt logs and upper logs being sawed by the mill.

When the 2,300 studs involved in the study were stress rated as by mechanical grading machines, the FPL sawing method was shown to produce studs averaging 10 percent higher in stress rating than those sawn by the conventional method. Since more FPL-sawn studs would thus make the top stress grade and fewer would be classed as rejects, it is estimated that production of top-grade studs would be increased by 20 percent or more and the rejects reduced similarly under this method of sawing.

WOOD CHEMISTRY RESEARCH

Progress in wood chemistry research was marked by significant developments in fundamental studies of lignin. Among noteworthy advances was that made in the use of electron paramagnetic resonance spectrometry to study lignin's molecular structure. An oxidation technique was evolved for inducing free radicals in certain lignin model compounds, from which distinctive paramagnetic spectra were obtained which may furnish a new means of characterizing lignin itself.

In studies of simpler phenolic compounds related to lignin, a compound was discovered that represents an entirely new class of phenols in that it is the first ever described that has two sugar residues attached through carbon atoms to a flavanoid group. A significant advance in the identification of benzene extractives of bark was also recorded when it was established that pinusenediol, a new compound discovered earlier in extractives obtained from jack pine bark, has a seven-member ring in its structure that is unique in this class terpenes. The finding may open the way to identification of complex new terpenoids and other substances in wood and bark.

New experimental evidence that paper deteriorates in a manner analogous to that of other organic substances may lead to reliable accelerated aging tests for determining effects of new processing developments. A study of free films of polyurethane varnish demonstrated that, while artificial aging causes embrittlement, it does not significantly impair their ability to block passage of moisture vapor. And a brief dip treatment of redwood boards in phenolic resin solutions was shown to provide appreciable dimensional stabilization of the surface zones under conditions of widely fluctuating relative humidity.

Lignin Research

New clues to the chemical character of lignin brought chemists measurably nearer to ultimate solution of this riddle which has baffled research workers for more than a century. Since lignin comprises some 26 to 30 percent of wood substance, its loss in chemical processing represents a handicap to commercial utilization that often proves insuperable. That the lignin molecule is much more complex than those of cellulose and hemicellulose has long been established. Inability to remove it unaltered from wood with chemicals now available has, however, greatly handicapped scientists in their efforts to identify and characterize it.

Dr. Cornelius Steelink adjusts apparatus for oxidizing lignin model compounds to produce free organic radicals for analysis by electron paramagnetic resonance spectrometer.
M 128 245

The importance of this problem was emphasized in 1963 by the establishment of a pioneering research unit in lignin chemistry at FPL, headed by John C. Pew (see 1963 Annual Report). During 1964, this unit was strengthened by the coming of Dr. Cornelius Steelink on a year's sabbatical leave from the University of Arizona. At Arizona, Dr. Steelink had shown that various lignin-containing products, including whole wood, contain free radicals (unpaired electrons) that create a magnetic field measurable with an electron paramagnetic resonance (EPR) spectrometer. Sodium salts of the products, he had found, contain greatly increased numbers of free radicals; and from this observation he concluded that lignins are in part comprised of a simple molecular structure derived from quinhydrone.

In past research at FPL, various model compounds had been synthesized that are believed to represent parts of the lignin molecule as it exists naturally in wood. These model compounds have been found to react to lignin solvents in a way paralleling that of lignin, by converting to comparable end products. They therefore provided Dr. Steelink with needed material for experiments with EPR spectroscopy.

Free radicals occur in nature quite commonly but very fleetingly. Dr. Steelink found, however, that oxidation produced relatively stable free radicals in the model lignin compounds he selected for use. With the aid of EPR specialists at the University of Wisconsin, where a spectrometer was made available to him, he was able to obtain and evaluate paramagnetic spectra that were distinctive and characteristic of individual model compounds. This discovery has in effect created a new tool for characterizing at least some parts of the lignin molecule itself.

Freeze drying technique is used by Chemist Linda Feldman to isolate phenolic compounds obtained from wood by solvent extraction. Solutions are frozen in dry ice in three spherical flasks. Vacuum is drawn and solvent vaporizes, passing on to vertical column where it is refrozen. Low-temperature removal of solvent prevents heat-sensitive phenolics from undergoing chemical change.
M 126 382

EPR spectrometry has other potentially broad applications to research and wood technology. The effects of fungal decay on free radical content of wood and its decomposition products is under study. The technique may ultimately provide quality controls in pulping and paper manufacture, wood finishing, and preservative treatments.

Related research by members of the pioneering research unit yielded confirmatory evidence that both biphenyl and diphenyl ether linkages exist in lignin. This was established by experiments in the enzymatic coupling of simple phenolic compounds, which also yielded evidence of biosynthetic incorporation of monomeric phenols in the lignin polymer. Several new types of cellulytic enzymes were investigated as agents for dissolving carbohydrates from wood as a means of preparing relatively undisturbed lignin for research purposes.

New Wood, Bark Extractives

The importance of phenolics to chemical make-up and behavior of wood is being emphasized by current research on these compounds, which are widely distributed throughout plants. Recent findings, for example, have demonstrated that they have key roles in the composition of fruits and vegetables and contribute resistance to plant disease and injury. They are often responsible for decay resistance of wood and for its color; it is thought that they may also be responsible for the chemical staining of lumber and to some extent for the color of pulp. Lignin is now regarded as a giant polyphenol, knowledge of which can be greatly assisted by study of simpler phenolics.

Discovery of a compound with a unique structure in that two sugar residues are attached through carbon atoms to a flavanoid group highlighted FPL research on phenolics during the year. The compound was derived from *Vitex lucens,* a species native to New Zealand and Australia, where its common names include puriri and Australian teak. Its unique structure makes the compound representative of an entirely new class of phenolics. Assistance in the identification was received from the University of Texas.

Dr. Margaret K. Seikel, in charge of extractives research on phenolics, was elected president of the Plant Phenolics Group of North America at the annual meeting in Norwood, Mass.

Attendance by a staff member at the Third International Symposium on the Chemistry of Natural Products in Kyoto, Japan, proved of assistance in determining the exact chemical structure of a compound extracted from jack pine bark. The staff member had presented a paper on the neutral diterpenes of pine barks. Consultation with other specialists led to the discovery that the jack pine bark compound, named pinusenediol, is identical with an

Dr. Margaret Seikel, FPL chemist, was installed as president of Plant Phenolics Group of North America.

extractive from club moss and is unique among know terpenes in having a seven-membered ring in its structure. Breaking this puzzle opens the way to the identification of already isolated new complex terpenoids and other substances in wood and bark.

Deterioration of Cellulosic Materials

Among criteria vital to the utility and acceptance of new products is their serviceability, a key factor of which is resistance to aging. The aging resistance of new or existing products may be seriously affected by changes in processing. Paper, for example, may gain or lose aging resistance if any of a long series of processing variables, such as pulping or bleaching, are materially changed. Basic information on aging processes is therefore vitally needed.

An important contribution to the study of aging was made during 1964 in research on kraft paper. This work showed beyond reasonable doubt that aging processes follow laws describing chemical reactions.

To conduct this research, specialized heating chambers were built that achieved a highly uniform temperature varying within 0.1° C. throughout a 3½-cubic-foot space. In these, two types of paper were exposed to temperatures ranging from 110° to 155° C. Simple chemical kinetic rate theories were used to analyze their relative rates of deterioration, to obtain apparent energies of activation for deterioration of several strength properties of paper, and to correlate the mechanical stress-strain properties of paper to its average molecular chain length (intrinsic viscosity).

It became evident from these experiments that, while mechanical properties of paper may not be measurably dependent upon gross chemical change in the cellulose system, the molecular interactions upon which such properties depend are chemical in nature or at least may be described successfully in terms of chemical reaction rate expressions.

The work was supported by a Weyerhaeuser Foundation fellowship grant held by a University of Wisconsin graduate student.

Charcoal Quality

Primary research findings reported last year (see 1963 Annual Report) showed that there is a positive relationship between the volatiles content of charcoal and its electrical resistivity, thus pointing the way to a method of quickly analyzing this quality factor. A volatiles content much above 20 percent makes charcoal objectionably smoky; much below that level, excessive losses are experienced in manufacture. The relationship to electrical resistivity affords an easy means of quality control.

A newly designed instrument for this use was tried on seven wood species. Results showed that they could be adequately evaluated for charcoal volatiles content, thus showing that the method is practical for commercial use.

Deterioration of Stored Pulp Chips

The growing practice of storing wood pulp chips outdoors, with its attendant advantages of mechanized handling as compared with pulp boltwood storage, has brought to attention deterioration problems that in certain regions can result in loss of wood substance and pulp quality. The nature and causes of this deterioration comprise a broad-range biochemical study now in progress, with the cooperation of a Maine papermill and the Northeastern Forest Experiment Station.

Broad objectives of the study are: (1) to investigate the mechanisms and causes of chemical changes resulting from outside chip storage, the rate of these losses, and the rate and loss of pulp yield and quality; and (2) to determine possible control measures, including the use of fungistatic chemicals.

To obtain precise information, selected logs were chipped and, after being blended and sampled by standard methods, were placed in nylon mesh bags and located in selected positions in a pile as it was built. Temperatures and amounts of carbon dioxide and oxygen present at various places in the pile are to be measured periodically. Each month during the 6-month life of the pile some of the bags of chips will be taken out. Part of each sample is to be kept at the pulp mill for pulping studies. The rest is to be packed in dry ice and shipped to FPL for pathological examination and chemical analysis.

Results of these studies are expected to be highly useful to pulp manufacturers, especially in the Northeast, as guides to proper piling and size and

Workmen spot bags of wood chips for burial in outdoor pulp chip pile in experiment to determine what chemical and biological changes take place during various periods of storage and effects on pulp.
M 128 423

maximum life of piles to prevent uneconomical loss of wood or harmful effects on pulp quality.

Surface Stabilization of Wood

It is becoming increasingly evident from research under way that surface treatment of wood with phenolic resin has marked benefits as a low-cost method of stabilizing the wood against swelling and shrinkage under humidity conditions that normally cause considerable change in dimensions of untreated wood. These dimensional changes are believed to cause premature failure of paints and other finishes. Experiments have shown that a simple dip treatment of about 5 minutes' duration is enough to introduce a sufficient amount of phenolic resin into the surface-zone fiber walls to provide appreciable stabilization.

Purpose of chemical stabilization of the surfaces is to hold treating cost as low as possible. Previous

Experiments in solubilization of various wood components, analysis of density gradients in surface-densified wood, thermogravimetric analysis of the products of combustion, and pyrolysis and quantitative studies of the adsorption of polymers by wood require wood shavings produced with precision. This massive lathe shaves cross sections 0.010 inch thick.
M 128 238

research that led to such products as FPL impreg and compreg was with wood thoroughly treated throughout its thickness. The treatment, while highly effective in stabilizing dimensions, is costly, adds considerable weight, and for some uses embrittles the wood excessively.

In related research, experiments were conducted on clear cast films of polyurethane varnish to establish its resistance to accelerated aging under concentrated ultraviolet light. The moisture-excluding effectiveness of the aged films was determined by placing them across a cup containing an atmosphere maintained at one relative humidity and placing the cup in an atmosphere maintained at a higher or lower humidity. Periodic weighing of the cup revealed whether moisture vapor was passing through the film.

Results showed that ultraviolet light aging did not materially affect the moisture-excluding effectiveness of the films.

Dimensional stabilization experiments with polyethylene glycol showed that a much more highly condensed form of this product, with a molecular weight of 4,000, stabilizes wood about as effectively as the material that has been generally used in experiments at FPL, which has a molecular weight of 1,000. Treatment was done at somewhat elevated temperatures to secure good penetration of the wood in a reasonable time. The advantage of PEG-4000 is that it leaves the wood with less of a surface-waxy feel and facilitates finishing with varnish.

During the year a unique assignment was undertaken for the American College of Physicians. It consisted of treating a limb of a plane (European sycamore) tree growing on the Isle of Cos in the Mediterranean. On this island the father of Medicine, Hippocrates, was born in 460 B.C. According to legend, he taught medicine under the tree.

The limb was treated with PEG and turned into a shaft for a ceremonial mace to be used by the College at induction of new Fellows.

Chemist Carole Southerland weighs cup sealed with cast film of polyurethane varnish inside controlled humidity chamber to determine whether moisture vapor has passed through film. Vapor pressure in cup is higher than that in chamber, causing loss of moisture within cup and weight change that measures amount of vapor passing through film.
M 128 549

INFORMATION ACTIVITIES

As part of the job of getting research results into use, FPL staff members issued 154 publications of all types during 1964, met with 3,658 consulting visitors from 47 States, one U.S. Territory, and 53 foreign Nations, acted as hosts to 20 meetings at FPL of industry and scientific organizations, and participated in meetings of 81 industrial, scientific, and educational organizations in this country and abroad by presenting papers, conducting committee or panel meetings, and contributing time and talent to organizational affairs.

A highlight of the year was the election of a staff member, Dr. H. O. Fleischer, chief of FPL's Division of Solid Wood Products Research for seven years, as president of the Forest Products Research Society. Dr. Fleischer became Director of the Division of Forest Products and Engineering Research at Washington headquarters of the Forest Service early in the year.

Besides the technical publications, 85 news-type articles were issued for the press, radio, and television. In addition, staff members participated in 11 radio and television programs in Madison, Milwaukee, and Duluth, Minn., Little Rock, Ark., and Washington, D.C.

Organizations meeting at FPL during the year were:

Special Committee on Technical Studies, National Lumber Manufacturers Association, January 16.

Timber Products Task Force, Edison Electric Institute, January 20.

Structural Planning Committee, American Society of Civil Engineers, January 23.

Committee D-7 on Wood, American Society for Testing and Materials, January 23.

National Paint-Lumber Industry Steering Committee of National Paint, Varnish, and Lacquer Association and National Lumber Manufacturers Association, April 1.

Symposium on Nondestructive Testing, May 14-15.

Pulp Chemicals Association, May 28.

Committee on Wood Bridges and Trestles, American Railway Engineering Association, June 9.

Western Woods Technical Committee, June 18-19.

Hardwood Action Council, July 1.

National Industry Committee on Fiber and Particle Panel Materials, August 19.

Subcommittee on Technical Studies, National Lumber Manufacturers Association, September 30-October 3.

U.S. Department of Agriculture Advisory Com-

Members of a research committee of the pulp and paper industry met with FPL staff members to discuss research problems November 5-6. From left, clockwise, are Robert L. Youngs, Chief of FPL's Division of Solid Wood Products Research; E. O. Ericsson, Vice President, Chemicals, Georgia-Pacific Corp., Portland, Oreg.; G. H. Sheets, Group Vice President, White Papers, Mead Corp., Dayton, Ohio; William H. Aiken, Vice President for Research and Development, Union Bag-Camp Paper Corp., New York; W. P. Lawrence, Research Associate, Champion Fibers, Inc., Hamilton, Ohio; J. F. Saeman, Chief of FPL's Division of Wood Chemistry Research; John C. Wollwage, chairman of the group and Vice President, Kimberly-Clark Corp., Neenah, Wis.; FPL Director Edward G. Locke; G. H. Chidester, Chief of FPL's Division of Wood Fiber Products Research; Kenneth G. Chesley, Technical Secretary, Technical Association of the Pulp and Paper Industry, New York; Thomas J. Muldoon, Technical Director, Pulp, Paper, and Paperboard Institute, New York; Donald T. Jackson, Vice President and Technical Director, Hammermill Paper Co., Erie, Pa.; G. K. Dickerman, Technical Assistant to the President, Consolidated Papers, Inc., Wisconsin Rapids; A. H. Nissan, Research Director, West Virginia Pulp and Paper Co., New York; William Gehrke, Director of Research and Development, American Can Co., Neenah, Wis., and Harold L. Mitchell, Chief of FPL's Division of Wood Quality Research.
M 128 076

Complete with hardwood and softwood trees, a packaging research exhibit featured FPL electronic cushion evaluation procedures at the Upper Midwest Industrial Packaging Exposition in Minneapolis September 16-18, sponsored by the Minnesota chapter, Society of Packaging and Handling Engineers.
M 128 542

mittee on Agricultural Science, October 5.

Committee D-7 on Wood, American Society for Testing and Materials, October 5-7.

Research Committee, American Institute of Timber Construction, October 8-9.

Subcommittee on Treated Poles, American Society of Agricultural Engineers, October 12.

Delegation of Mississippi Marketing Council, Agricultural and Industrial Board, October 28-29.

Subcommittee on Fire-Retardant Paints, National Paint, Varnish, and Lacquer Association, December 1.

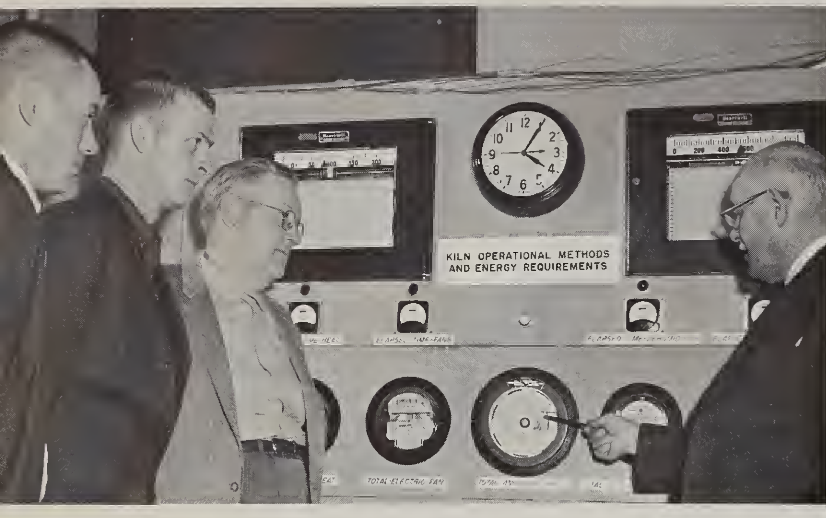
The 3,658 consulting visitors included representatives of the above organizations as well as other industry organizations, and governmental and educational agencies. In addition, the Laboratory was visited by 8,104 persons, of whom 5,713 came with a general interest in wood and research and participated in official guided tours given at 2 p.m. each workday. The total number of visitors during the year, therefore, was 11,762 — just 588 more than the previous year.

Foreign countries, and the number of nationals from each, were: Afghanistan 3, Argentina 2, Australia 10, Belgium 7, Brazil 4, British Hong Kong 1, Cameroon 1, Canada 42, Chile 1, Colombia 2, Denmark 2, Ecuador 1, Egypt 1, England 11, Finland 7, France 10, Germany 9, Ghana 1, Holland 2, India 26, Indonesia 3, Iraq 3, Ireland 2, Israel 2, Italy 5, Jamaica 1, Japan 55, Laos 1, Liberia 5, Malaysia 1, Monaco 1, Nepal 1, New Zealand 3, Nicaragua 1, Nigeria 2, Norway 6, Pakistan 3, Paraguay 1, Philippines 9, Poland 1, Republic of China 1, Republic of Somali 1, Republic of South Africa 4, Sudan 6, Sweden 12, Switzerland 4, Thailand 1, Togo 1, Tunisia 1, Turkey 24, Uganda 2, Viet Nam 2, Venezuela 3.

Noteworthy among groups of foreign visitors were delegations from the Japan Packaging Institute and a Japanese lumber chip industry study team, one from the French National Federation of Sawmills, and a pulp and paper production study team from Turkey.

Exhibits illustrating FPL research findings were displayed, among other places, as part of a USDA Home and Food Show in Washington, D.C., a Kentucky Crafts Show at Berea, the Upper Midwest Industrial Packaging Exposition at Minneapolis, and the Southeastern Fair at Atlanta, Ga.

Among technical, educational, scientific, and industrial organizations to which staff members spoke were the annual meeting of the Society of American Foresters; national and sectional meetings of the Forest Products Research Society at Chicago, Bemidji, Minn., Chillicothe, Ohio, and St. Paul, Minn.; American Institute of Timber Construction annual meeting, San Francisco; annual meeting of American Wood-Preservers Association, San Francisco; annual convention, American Railway Engineering Association, Chicago; American Society for Test-



Experimental methods of improving the kiln drying of lumber were explained to 42 dry kiln operators, plant superintendents, and other personnel of industrial firms in 21 States attending a kiln drying demonstration at FPL April 7-17. Here Raymond C. Rietz, right, veteran seasoning research specialist, discusses an experiment in electrical drying of wood with, from left: Thomas Lockett, sales representative, Weyerhaeuser Co., Atlanta, Ga.; Francis Kelly, assistant dry kiln engineer, Alger-Sullivan Co., Century, Fla.; and S. A. Dowdell, industrial forester, North Carolina Department of Conservation, Raleigh.

ing and Materials, Chicago and Philadelphia; American Institute of Chemical Engineers, Memphis, Tenn.; Technical Association of the Pulp and Paper Industry, New York City; British Textile Institute, Manchester, England; Mexican Technical Association of the Pulp and Paper Industry, Mexico City; American Chemical Society, Chicago and Philadelphia; American Pulpwood Association, Jackson, Miss.; International Symposium on the Chemistry and Biochemistry of Cellulose, Hemicellulose, and Lignin, Grenoble, France; National Wooden Pallet Manufacturers Association, Hollywood, Fla.; Fibre Box Association, Chicago; American Hardboard Association, Portland, Oreg.; Western Association of State Highway Officials, San Diego, Calif.; Symposium on Sorption and Rheology of Wood, Munich, Germany; and Instrument Society of America, New York City.

Director Edward G. Locke reported to the permanent committee of the International Union of Forest Research Organizations on activities of its Forest Products Section, of which he is chairman, at a meeting in Istanbul, Turkey. He also conferred with forestry officials of the United Nations Food and Agriculture Organization in Rome, Italy, and addressed the staff of the Israel Institute of Fibers and Forest Products Research in Jerusalem.

Alan D. Freas, Assistant to the Director, was one of two United States representatives at a Seminar on Building Materials October 4-24 in Rio de Janeiro, Brazil. He represented the American Standards Association.

Dr. Milton Y. Feather, FPL carbohydrate chemist, went to Stockholm, Sweden, for a year of study with Prof. Bengt Lindberg at the Swedish Forest Products Laboratory, under authorization granted by Public Law 85-807. Dr. Catherine Duncan, FPL pathologist, had preceded him abroad for a year of

Technologist Diana Smith examines statistical data on the FPL computer with Ethel Hunter, undergraduate summer employee from Fisk University, Nashville, Tenn. Miss Hunter worked on analysis of statistical data dealing with anatomical characteristics of wood.

advanced study in Zurich, Switzerland, under the same law and an extension of 5 months made possible by a National Science Foundation grant.

Nine graduate students were supported with grants of funds furnished under the Whitten Act. Two were at the University of California, one dealing with chemical analysis of resin acids obtained from rosin of pine stumpwood and the other with effects of environmental and other conditions on formation of summerwood and springwood, the annual ring, and specific gravity. Two studies at the University of Minnesota involved an evaluation of the size and distribution of intertracheid pores in conifers and a study of some factors involving initial infection of wood by fungi.

A study of wood machining with water jets was continued at the University of Michigan. A graduate student at the State University of New York at Syracuse University continued an investigation of the catalytic hydrogenation of lignin during pulping with aqueous alkali and organic solvents. A study of wood drying with air jets was under way at the University of Oregon. At Southern Illinois University a study was conducted of the reaction rates of polysaccharides in alkaline solutions, and at the University of Wisconsin a student was investigating the effects of various environmental factors on the energy balance in wood products in exterior service.

Five graduate students completed research work at FPL during 1964 for advanced degrees at the University of Wisconsin. Three were engineering students and two engaged in work on solid wood products research. Three others continued work, two on engineering subjects and one on wood quality research.

Eighteen undergraduate students worked at FPL during the summer on research jobs, mainly as laboratory aids. They came from North Carolina State, Grinnell, New York State, Portland State, and Oberlin College; Fisk University; University of California at Los Angeles; Iowa State University, Rice University, West Virginia University, Rochester Institute of Technology, Miami University, Lawrence University, the University of Utah, and the University of Wisconsin.

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